**UNIVERSITY OF THE WESTERN CAPE**

**DEPARTMENT OF ECONOMICS**

# Economic analysis of the Shear Separation Floatation (SSF) technology for winery wastewater treatment

by

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A full dissertation submitted in fulfilment of the requirement for the degree of Masters of Commerce in the Department of Economics, The University of the Western Cape.

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# DECLARATION

I declare that "*The Economic Analysis of the Shear Separation Floatation (SSF) technology for winery wastewater treatment"* is my own work, that it has not been submitted for any academic qualification or assessment in any university, and that I have rightfully acknowledged all the sources utilised or quoted in this study by complete references.



**Signature:** 

**Date:** 25 April 2024

# ACKNOWLEDGEMENTS

The Lord has been faithful to me throughout this journey. He is my pillar of strength and stronghold, and my heart is full of gratitude. This is to the glory of the Lord. "*Now all glory to God, who is able, through his mighty power at work within us, to accomplish infinitely more than we might ask or think*" ~Ephesians 3:20-21.

This thesis is dedicated to the memory of my late mother, Nonceba Hilda Mgudlwa (1966 – 2021) who was very supportive to me in my academic endeavors, she was my greatest support system. She would have been very proud of me at this point. May her soul rest in eternal peace!

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# ABSTRACT

Difficulties in the treatment of industrial wastewater have become serious challenges in the water and sanitation sectors. The wine industry is among the industries that are seriously affected by the difficulties of effluent treatment to comply with environmental standards. One of the effective methods to control the winery effluent is to install a customised wastewater treatment plant or upgrade an existing plant for better results. Economic analysis is necessary to evaluate the viability of installing the plant as the method for the treatment of wastewater. This dissertation is centered on an economic analysis of a wastewater treatment plant proposed as a solution to improve the wastewater treatment challenges at Winery X by means of a case study. The case study is based on a Shear Separation Flotation (SSF) pilot plant installed at Winery X. The key arguments in study are built on the conventional Cost-benefits analysis (CBA) as the main method of enquiry.

The analysis includes Option 1- keeping the existing system and make no change, Option 2- upgrading the existing system with a flotation device which will recover the treated wastewater quality, and Option 3- upgrading the existing system with a flotation device and a Reverse Osmosis unit. Option 3 is expected to recover the treated wastewater quality and reduce the reliance on freshwater intake by at least 50%. Applying all the input variables, the primary economic analysis was conducted. Then, the sensitivity of the results to the varying values of the key input variables was examined. The initial results for the primary economic measures suggest that Options 1 and 2 are not viable while option 3 is viable. However, the sensitivity analysis suggests that option 2 would be viable after 10 years, provided fines are levied for non-compliance while option 3 would be viable and be profitable in 5 years. Therefore, option 3 is the most practical and preferred solution.

**Keywords:** Wine industry, Water effluent, Wastewater treatment, Wastewater treatment plant Economic Analysis, Cost Benefit Analysis, Environmental restrictions(requirements), Winery X.

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| | |
|---|---|
| ADB | Asian Development Bank |
| BCR | Benefit-cost Ratio |
| CAPEX | Capital Expenditure |
| CBA | Cost-Benefit Analysis |
| CEA | Cost-effectiveness Analysis |
| CER | Cost-effectiveness Ratio |
| COD | Chemical Oxygen Demand |
| CUA | Cost-Utility Analysis |
| DEAT | Department of Environmental Affairs and Tourism. |
| DPP | Discounted Payback Period |
| DWAF | Department of Water Affairs and Forestry |
| DWS | Department of Water and Sanitation |
| EA | Economic Analysis |
| EC | Electrical Conductivity |
| EIRR | Economic Internal Rate of Return |
| ENPV | Economic Net-present Value |
| ha | Hectares |
| IRR | Internal Rate of Return |
| K | Potassium |
| Kg | Kilogram |
| KOH | Potassium hydroxide |
| L | Litre |
| l/h | Litres-per-hour |
| $M^3/a$ | Cubic Metres-per-annum (1 $m^3$ of water = 1000 litres of water) |
| Mg/L | Milligram per litre |
| MIRR | Modified Internal Rate of Return |
| ml | Milliliter |

| | |
|---|---|
| mm | Millimeter |
| ms/m | milliSiemens per meter |
| N | Nitrogen |
| NPV | Net-Present Value |
| NWA | National Water Act |
| OPEX | Operational Expenditure |
| P | Phosphorus |
| p.a | Per annum |
| pH | Potential of hydrogen |
| PI | Profitability Index |
| PP | Payback Period |
| Ppm | Parts Per Million |
| QALY | Quality-adjusted Life Year |
| R | Rand |
| R/ $M^3$ | Rands-per-cubic mitre |
| RO | Reverse osmosis |
| RoR | Rate of Return |
| SAR | Sodium Adsorption Ratio |
| SAWIS | South African Wine Industry Information & Systems |
| SS | Suspended Solids |
| SSF | Shear Separation Flotation |
| TDS | Total Dissolved Solids |
| TSS | Total Suspended Solids |
| WTA | Willingness to Accept |
| WTP | Willingness to Pay |
| WWTP | Wastewater Treatment Plant |
| WWWT | Winery Wastewater Treatment Technology |
| ZLD | Zero-Liquid-Discharge |

# CHAPTER 1: INTRODUCTION

## 1.1 Background

The wine industry provides auspicious economic opportunities for South Africa domestically and globally. South African wine industry produces roughly 3.4% of the global wine production and has witnessed expansive growth in the past decade, with exports of wine more than doubling between 2005 and 2015 (Amfori et al., 2019; McDonald et al., 2006). In 2019, the yearly grape harvest was 1.3 million tons, which could yield 973.6 million litres of wine. Eight hundred and thirty seven million litres (86%) of the harvest was used for wine production (Demhardt, 2003). The wine industry has created significant streams of revenue for the country. In 2018, South Africa made global wine sales of 420 million litres, which generated R11.3 billion in revenue. These values vary over time. A recent report by South African Wine Industry Information & Systems [SAWIS] (2021) on the wine industry's contribution to the domestic economy reflects a 1.1% contribution to the total national economy or gross domestic product (GDP in nominal terms), equivalent to R55.0 billion.

While the industry utilizes many skilled labourers, it has also been a beacon of hope for many unskilled labourers in South Africa. In the early 2000s, the wine industry created jobs for about 216 thousand employees, and two-thirds of these were from the Western Cape Province (Demhardt, 2003). Currently, the industry employs roughly 269 thousand employees, which account for 1.6% of the national employment (SAWIS, 2021). The wine sector is a significant pillar of the South African economy and is one of South Africa's top agricultural product exporters.

However, effective and profitable winemaking processes result in vast volumes of wastewater, which generally entail sizeable concentrations of organic materials and other pollutants generated from product loss and cleaning processes (Mosse et al., 2011). Maximum amounts of wastewater are formed during the harvesting period (mid-January –April) in the winemaking industry (Howell et al., 2016). Due to the volume of effluent produced annually and its environmental effects, wastewater treatment and management is a significant concern for the wine sector, particularly given stricter environmental restrictions (Mosse et al., 2011).

With the concern mentioned above, technological innovations for water saving, wastewater treatment and reclamation have been employed to tackle the increasing demand for water use and respond to the ecological and societal effects of wastewater. Therefore, the growing environmental restrictions and concerns provide a fertile ground to explore alternative wastewater treatment technologies. Exploring alternative wastewater treatment technologies in the wine industry is particularly vital due to the contribution of the wine industry to the national economy.

A Shear Separation Floatation (SSF) technology supplied by Abrimix is the proposed novel and superior technology to treat the effluent at Winery X. Flotation is a separation method that involves three stages of matter: Gas, liquid, and solid (Kyzas & Matis, 2019). It originates from mineral processing, known as "froth floatation". It is recognised as a worthwhile separation procedure, helping in the reclamation and recovery of various materials. The Abrimix treatment equipment has been demonstrated to be cost-effective in decreasing total suspended solids (TSS), chemical oxygen demand (COD) and fats, oils and grease (FOG) from several forms of "hard to treat" wastewaters (Jalema Technologies & Abrimix, 2018). Jalema further indicates that the technology has also minimised water footprint and aided clients in meeting their environmental requirements consistently. Abrimix Technology can provide high-performance, cost-effective results for various hydrometallurgical and water treatment applications (Jalema Technologies & Abrimix, 2018).



## 1.2 Problem Statement

Climate change as a global phenomenon has caused severe environmental sustainability pressure, particularly in semi-arid regions such as South Africa. For instance, South Africa has been experiencing significantly lower surface freshwater levels in recent years (Adewumi, 2011). Given the scarcity of water in South Africa (ranked the 22$^{nd}$ driest country in the world as per 2019 estimates produced by World Resources Institute) (Kuzma et al., 2023), water paucity will likely intensify due to climate change (StatsSA, 2019). Subsequently, the Western Cape region of the nation is expected to be severely dry in future (Adewumi, 2011). As one of the wine-rich provinces whose economy is significantly dependent on the winery industry, the impending Western Cape drought is incredibly concerning.

The low water levels have harsh economic implications, particularly for the agricultural and wine industries (Schreiner et al., 2018). Attached to this predicament is the perpetual contamination of surface water with wastewater produced by domestic, institutional and industrial activities. According to Strong and Burgess (2008), a significant and cumulative proportion of wastewater is generated from the winemaking and distillery activities. The wastewater from the wine industry is primarily the result of several washing processes involving the destemming and wine-pressing of grapes, along with the cleaning of fermentation vessels, barrels, including other apparatuses related to this process (Strong & Burgess, 2008). The wine industry is among the industries that require a substantial volume of water use for the entire vinification process. On average, 85% of wine production processes depend on water (Bonamente et al., 2015).

Given the national water deficiency and the importance of water in the realm of wine business, it is vital to preserve and properly manage the available water resources. The limited water-efficient and good water management practices in the wine industry may threaten its future. Implications are both environmental and economic (Conradie et al., 2014). Thus, prioritising ecological and economic sustainability is in the best interest of the industry stakeholders. One way this can be achieved is through implementing innovative and efficient wastewater treatment technologies.

As such, a case study based on a new wastewater treatment technology piloted at Winery X is conducted in this study. Winery X was selected as the winery of choice after approaching the University of the Western Cape for assistance to curb the wastewater discharged into the environment to achieve compliance and eliminate similar issues. At the beginning of the project, the COD of the treated effluent at Winery X was beyond 5000mg/L. As such, Winery X was in trouble with the Department of Water and Sanitation (DWS). There were also some complaints from the surrounding community about an unpleasant odour from Winery X wastewater.

However, constructing a wastewater treatment plant (WWTP) involves a considerable cost in addition to maintenance and operational costs. In order to properly manage available financial resources, it is vital to analyse the economic viability to establish whether such a proposed project is feasible or not (Fitriani et al., 2019). This is the basis of this dissertation.

## 1.3 Research Questions and objectives

### 1.3.1 Research Questions

The main question of interest for this study is: How does the cost of constructing a Shear Separation Floatation (SSF) water treatment plant, or lease of such equipment, impact the overall economics of the winery, and will it improve economic and environmental sustainability?

**Specific questions are:**

1. What is the economic influence of the wine industry to the South African and the Western Cape economies?
2. How significant are water resources and wastewater management practices in the wine industry?
3. What are the economic costs and benefits of installing Shear Separation Floatation (SSF) technology in Winery X, and is it a viable option for the winery?
4. What policy and business recommendations can be made based on the CBA results?

### 1.3.2 Research Objectives

The study evaluates the economic feasibility of the novel wastewater treatment technology (Shear Separation Floatation) applied to treat waste streams in the winery. The analysis was largely based on assessing the economic and financial costs involved in the process. The following objectives were addressed:

1. To review the influence of the wine industry on the economy of the Western Cape and South Africa.
2. To examine the significance of water resources and wastewater management practices in the wine industry using the available literature.
3. To evaluate the economic costs and benefits of the Shear Separation Floatation (SSF) Technology using Winery X as a case study and determine its viability.
4. To provide policy and business decision recommendations established on the outcomes of the study.

## 1.4 Relevance of the study

The rising concerns regarding limited water supply and large volumes of effluent in the wine industry have inspired Winetech, in collaboration with the South African Institute for Advanced Materials Chemistry (SAIAMC) at the University of the Western Cape and ABRIMIX to investigate the feasibility of the novel technology Shear Separation Floatation (SSF). This study explores the economic aspects of the project.

This study is the first ever to do an economic analysis of SSF technology to treat winery wastewater, focusing on Winery X in South Africa. The broader impact of the project is aimed at boosting the profitability and sustainability of the South African wine industry. Since winery wastewater treatment processes are relatively costly, innovative and advanced wastewater treatment technologies are required to advance the sector's sustainability, which is vital and relevant within an already challenged South African economy (Christ & Burritt, 2017). Economic analysis is vital in evaluating the viability of any project. The project at Winery X is no exception. Therefore, this study serves to fulfil this requirement. The objective of this study includes providing decision-making insights to policymakers to improve water reuse and drought resilience in wineries.

## 1.5 Structure of the Thesis

This dissertation is structured as follows- Chapter 1 sets the scene for the study by providing a brief introduction, problem statement, research objectives and significance of the study; Chapter 2 discusses the South African wine industry and its importance to the economy of South Africa; Chapter 3: provides discussions on the importance of water resources, the wastewater treatment practices in the wine industry and ecological effects of winery effluent; Chapter 4: reviews the literature (economic analysis) to the study. This chapter further reviews the empirical studies based on economic analysis of wastewater treatment methods and provides the case-study of Winery X based on wastewater treatment challenges. Chapter 5 provides the methodology adopted including data utilised in this study; Chapter 6 displays the results of the cost-benefit analysis of the wastewater treatment technology (SSF) proposed to Winery X in comparison to the without project scenarios; and Chapter 7 discusses the findings. Finally, Chapter 8 outlines the main conclusions of the study and provides policy recommendations thereof.

# CHAPTER 2: AN OVERVIEW OF THE WINE INDUSTRY IN SOUTH AFRICA

## 2.1 Introduction

The viniculture plays a significant economic role for many nations, embodied in wide-ranging and extremely varied climates and affected by global climate change at different levels (Rienth & Scholasch, 2019). In South Africa, this is evident in areas such as employment, exports, national output and the likes (Gbejewoh et al., 2021). It is therefore of utmost importance to consider economic aspects in wine related studies. This chapter is intended to set a scene for this study and bring into perspective the significance of the wine industry to South Africa's economy. The chapter begins by briefly discussing the South African wine industry and viticulture origins. The study covers both the nation's and the Western Cape's wine industries. Wine tourism as another remarkable contributor to the economy of South Africa will be briefly discussed.

## 2.2 Origin of the wine industry and viticulture

Wine production in South Africa originates in the Cape region of the country, where Vitis Vinifera was first planted back in the 1600s (Estreicher, 2014). Since then, the industry has experienced expansion, resulting from the increasing proportion of vineyards in the Cape region of South Africa (including Rondebosch, Stellenbosch, Paarl, Constantia areas etcetera) (Estreicher, 2014). In 1679, regulations were introduced with the intention of increasing the quality of grapes produced by farmers. During this era people who were skilled in winegrowing were brought from the Netherlands by the Dutch East India Company and later from France (Huguenots) (Fourie & von Fintel, 2011).

The French Huguenots then became the most productive wine makers compared to the then already existing wine makers in South Africa (Fourie & von Fintel, 2014). However, in the 1800s the wine industry saw a decline resulting from local natural disasters and political events in Europe (Keywood & van der Merwe, 2015). The recovery rate from that economic downturn was sluggish until the 1990s when the international embargo against South Africa was lifted. This was followed by the emergence of a large number of small wineries, wine labels and noteworthy upsurge in foreign investment (Estreicher, 2014). Wine consultants (experts) started coming to South Africa

from the European and North American regions to the South African wineries. The South African wine industry has since grown and now produces quality wines that are recognised in the global market.

In addition, the year 1918 marked the formation and enactment of the Ko-operatieve Wijnbouwers Vereniging van Zuid Afrika (KWV) which introduced regulation and order to the South African Wine industry. The main results of the KWV included the reduction of excess wine production. While, the KWV was useful in restructuring the industry, the expansion of the wine business was severely hampered by the rise of the apartheid in 1948 which led to international sanctions (Estreicher, 2014; Keywood & van der Merwe, 2015). Consequently, the wine industry's closed market and seclusion from international markets together with the nearly sole focus on curtailing excess wine production, resulted in an extensive production rather than quality-orientated industry (Meissenheimer et al., 2004).

In 1991, the quota system enacted by the KWV was abolished, creating a doorway for the establishment of new vinicultural areas and an environment for those in effect to thrive. In 1997 the KWV was translated from a cooperation into a company. It ceased from purchasing surplus production for distillation, which necessitated that winemakers produce high quality wines. On the other hand, in 1990, wine production utilised only roughly 30% of the grape harvest (the rest being used in fruit juices or as table grapes), in 2003 this number climbed up to approximately 70% (Estreicher, 2014). Some further important events in the South African wine sector are depicted on Appendix A.

## 2.3 Size and importance of the wine industry in South African: A profile

Stimulated by the dawn of democracy in 1994, the South African wine market experienced tremendous growth and gained a great momentum locally and globally (McDonald et al., 2006). The impact includes the job sector among other sectors. Back in 1999 the wine industry employed roughly 96,000 people and sustained around 216,000 other individuals over the years of whom nearly two-thirds were possibly located in the Western Cape (Demhardt, 2003).

According to SAWIS (2013), in 2013 the amount of grapes crushed in South Africa per winery ranged from 5 to 75 000 tonnes in each grape harvest season, where regular crushing of the produce ranges from 1 to 100 tonnes of grapes for each winery (Conradie et al., 2014). South African wine

grape production is dominated by white wine grape production which contributed more than 70% of the aggregate production of grapes in 2013 (SAWIS, 2013). However, in 2020 1.4 million tonnes of grapes produced were crushed which represents an increase of 8.2% with respect to the tonnes registered in 2019. This increment formed part of the 7% rise on the wine production from 2019, with 1042 litres of wine produced (Wesgro, 2021).

### 2.3.1 Wine Industry Structure

Viticulture is a vital aspect of the winemaking process and as such forms part of the discussions around the wine industry, its structure and progression in years. Nonetheless, in understanding the wine industry, its importance and its impact to the economy of the nation, it is important to consider the trends in different years as they are a reflection of the industry's performance. Table 2.1 underneath depicts the wine industry the structure for a six-year period from 2015 to 2020**.**

**Table 2.1: Wine industry structure (2015 – 2020)**

| Category | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|
| Number of primary grape producers | 3232 | 3145 | 3029 | 2873 | 2778 | 2693 |
| Estate wine producers | 210 | 209 | 207 | 213 | 220 | 220 |
| Number of wine cellars which crush grapes | 566 | 568 | 546 | 542 | 533 | 529 |
| Producer cellars (Cooperative wineries) | 48 | 48 | 48 | 47 | 45 | 45 |
| Producing wholesalers | 24 | 27 | 26 | 27 | 28 | 27 |

*Source: South Africa's Wine Industry Information & Systems (SAWIS, 2021) report*

The structure of the South African wine industry consists of five different aspects which are shown in Table 2.1 above. Table 2.1 displays a decreasing trend on the *number of grape producers* that grow wine grapes throughout the six-year period. However, the *estate wine producers* just below the *number of primary grape producers* show a slightly different trend in the six-year period. The number of *estate wine producers* dropped from 2015 till 2017, then showed an upward trend for

two consecutive years 2018 and 2019, then stabilised at 220 in 2020. Looking at *the number of wine cellars which crush grapes* for wine, from 2015 two more wine cellars came in to operation in 2016 which increased the quantity of wine cellars. Following this increase there was a decline from 2017 to 2020. Additionally, the amount of producer cellars was constant at 48 for the first three years then started to drop in 2018 and was the equal for the last two years of the reported period. The last category - *producing wholesalers* remained at 27 every second year of the reported period with a range of 24 to 27.

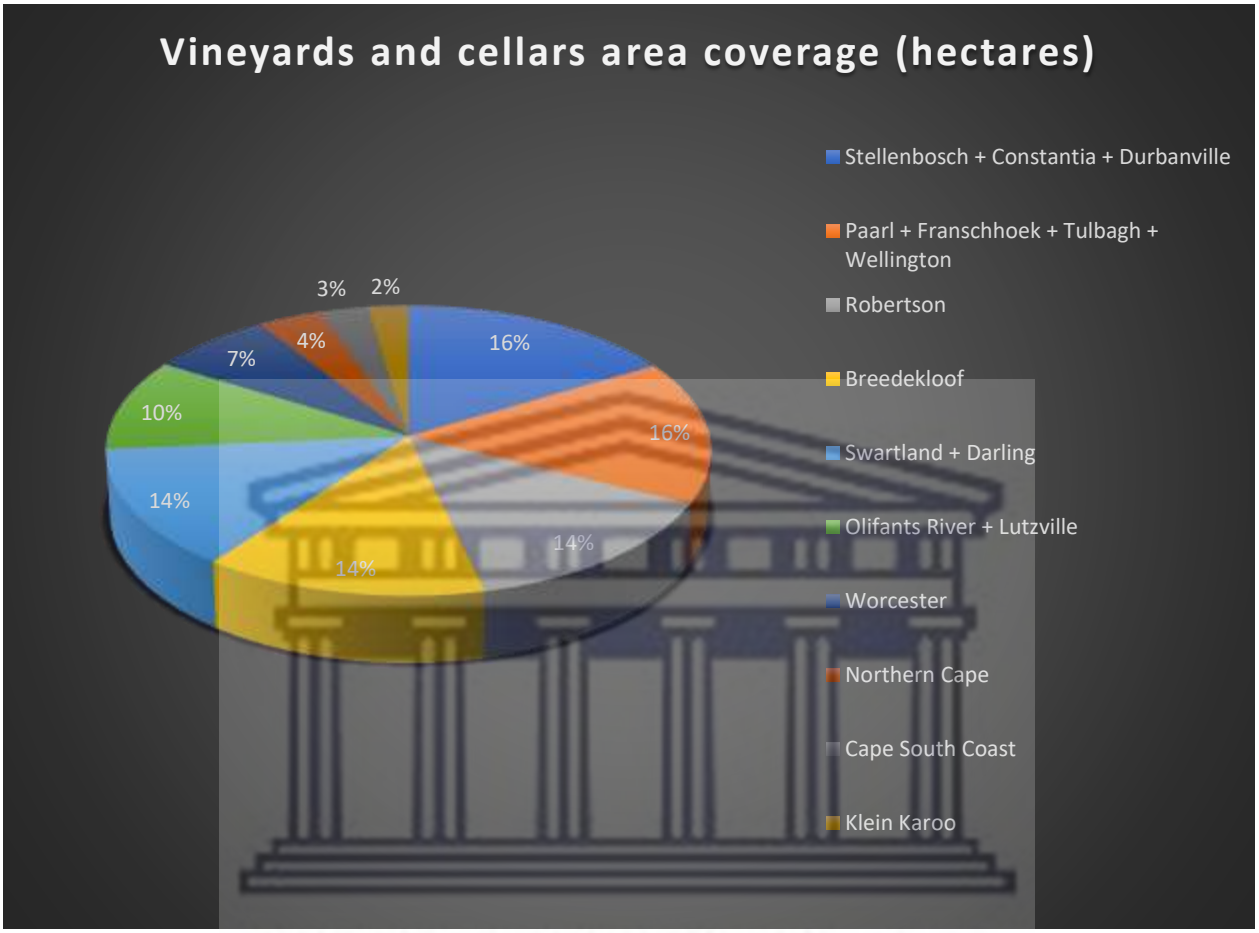
Although the variations in some of the aforementioned categories are only trivial, a significant decline between 2015 and 2020 was noted in the *number of primary grape producers*. This period was one of the driest seasons in the history of the South African agricultural industry particularly from 2015 till 2017 (Baudoin et al., 2017). Due to the severe drought experienced by farmers, the crop yields dropped and fewer farmers remained in the industry (Archer et al., 2019).

### 2.3.2 South African Vineyards and Cellars

The South African vine grape area amounts to 92 005 hectares (ha) of land (2020 estimates). This was preceded by 92 067 ha in 2019, 93 021 ha in 2018, 94 545 ha in 2017, 95 775 ha 2016 and 98 594 ha 2015.The data indicates a perpetual decreasing trend of the total area under vine from roughly 98 000 ha in 2015 down to 92 000 ha in 2020 **(**SAWIS, 2021). The reduction in vineyard area complements the drop in the quantity of primary grape producers in Table 2.1 above.

Most of the winegrowers in South Africa are located in the Western Cape Province, some in the Northern Cape and very smaller number in other parts of South Africa (Ferreira & Hunter, 2017). Below in Figure 2.1 is a breakdown of the area under vines in different wine producing areas (Northern Cape includes other parts (provinces) of South Africa).

**Figure 2.1: Vineyards and cellars in different wine producing areas in South Africa (%)**




*Source: own computation, data extracted from South Africa's Wine Industry Information & Systems (SAWIS) 2021 report.*



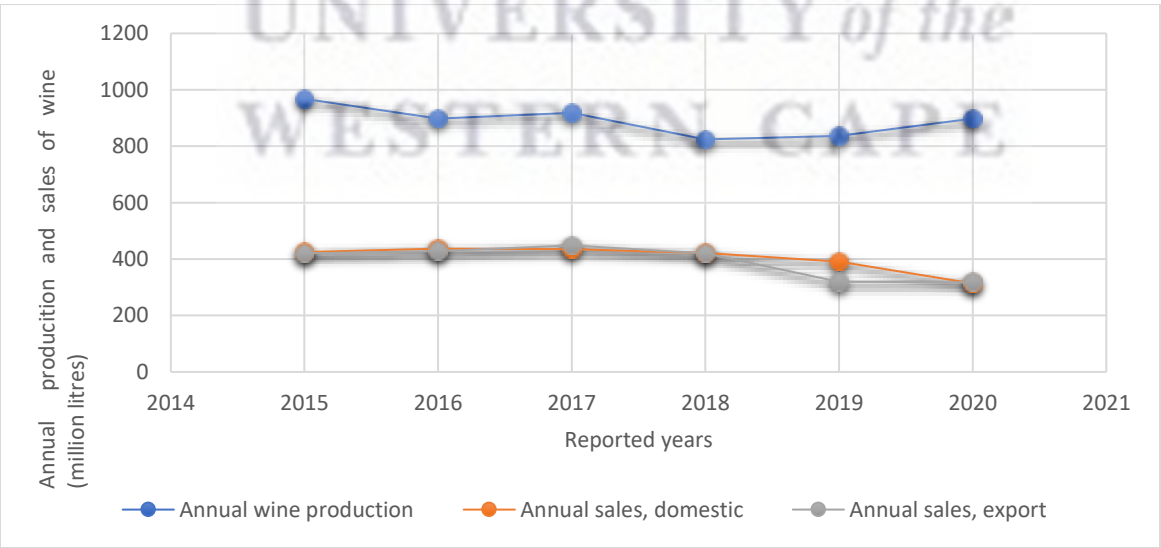
Stellenbosch combined with Constantia and Durbanville cover the largest vine area with 15 085 (16%) ha as depicted in Figure 2.1. This area information consists farms, independent cellars and co-operative cellars. Stellenbosch and Constantia are among the oldest vine production areas in South Africa which comprise South Africa's leading so called wine-scape which includes Paarl and Franschhoek (Ferreira & Hunter, 2017). Paarl, Franschhoek, Tulbagh and Wellington are slightly smaller with 14 742 ha (16%). While this combination is the second largest area, it has the highest number of farms exceeding those of Stellenbosch combined with Constantia and Durbanville. Robertson, Breedekloof and Swartland & Darling each comprise around 12 000 ha (14%) and Oliphant's River plus Lutzville have an area of 9 403 ha (10%). The Klein Karoo has the smallest vine area with only 2 181 ha (2%). Lastly, the Northern Cape as a province only has

3 463 ha (4%) of land under vine. Thus, the Western Cape as the leading wine producing province in South Africa carries a greater proportion and footprint of the wine vineyards land followed by the Northern Cape Province. This is the reflection of the amount of land currently producing wine in South Africa produced in different regions.

### 2.3.3 South African Wine Production, Sales (Quantity)

The economic progress of the South African wine industry is largely affected by the rainfall fluctuations and temperatures**.** According to the SAWIS (2021) report the wine grape harvest was 1 461 599 tonnes, which is 8.9% higher than the 2020 yields. In 2020, 1.3 million tonnes of grapes produced were crushed for wine production. This was preceded by 1.2 million tonnes crushed in 2019**,** 1.2 million tonnes in 2018, 1.4 million tonnes in 2017, 2016 and 2015 (SAWIS, 2020). The amount of grapes crushed remained constant (1.4) during the drought intensive years in South Africa particularly in the Western Cape (2015 to 2017), then dropped in 2018 and maintained the same level of production in 2019, slightly recovered in 2020 at 1.3 million. The yearly production of wine for the years 2015-2020 is illustrated in Figure 2.2 below together with the sales made for the years 2015 to 2020**.** The national vineyard is made up of 55.4% of white grape vines and 44.6% of red grape vines.

**Figure 2.2: National wine production and sales in the period 2015 to 2020**




*Source: author's computation with data from (SAWIS, 2020) report*

According to Figure 2.2 above, the wine production (represented by the blue line) fluctuates throughout the five-year period. Firstly, the trend shows a drop in the litres of wine produced from 2015 to 2016. The wine production picked up in 2017. However, the trend line was steeper in 2018 which signified the lowest wine production ever recorded in the reported five-year period. Production started to improve in 2019 and improved further in 2020. The 2021 wine harvest was projects to have a standard improvement of 778 litres per tonne of grapes (SAWIS, 2021).

Additionally, total sales include domestic sales and exports. While these two types of sales slightly differ in most years they are very close. For instance, in 2015 the difference in the annual domestic sales (425 million litres) and the exports (420 million litres) was only 5 million litres. Both the domestic sales and the exports increased in 2016 to 436.9 million litres and 428.4 million litres respectively. While exports (448.4 million litres) further increased in 2017, there was a slight decline in domestic sales (435.6 million litres) which resulted in South Africa generating more revenue from the exports than domestic sales. A similar incidence occurred in 2008 where the volumes of wine exported exceeded the domestic sales with respect to sales in volumes (NDA, 2007). In 2018, the annual sales dropped to an almost the same amount for domestic sales and exports which is 420.2 million litres and 421.1 million litres correspondingly. The annual sales for both domestic sales and exports further declined in 2019 and 2020, which resulted in a downward trend in sales for three consecutive years.

## 2.4 Macro economic impact of the wine industry (Value added)

South Africa is the ninth biggest wine manufacturing nation with about 4% production of the world wine production (VinPro, 2021). The South African wine sector generated more than R55 billion which contributed to the gross domestic product (GDP) the nation. It also employed roughly 270 000 employees throughout the wine value-chain, 80 183 are farm and cellar workers (VinPro, 2021).

### 2.4.1 National production contribution (Rands)

National production includes the input of wine grape farmers, actual wine manufacturers to the overall amount of sales, goods and services in the economy. Both the value of total goods ready for consumption semi-finished products used in the value chain of wine are included. The South

African wine industry's production input to the whole of the country's economy amounted to R125.7 billion in 2020 (SAWIS, 2021). This amount is equivalent to 1.4% of domestic production. The wine industry involves contributions (wine grapes, compost, packaging, water and electricity, machinery, marketing etcetera) from other different sectors within the economy. These inputs create value in those sectors as well, included in those sectors are financial, business services, transport, and communication etcetera (SAWIS, 2021). For instance in 2020, the local wine industry bought goods and services and capital material to the value of R29.3 billion from primary local merchants (SAWIS, 2021). Also, due to the wine industry's economic activities, the agricultural sector (grape farming and other related agricultural farming) yielded a production amount of R9.8 billion.

### 2.4.2 Gross Domestic Product (GDP) contribution (Nominal terms)

South African wine industry influence to the national economy in terms of the GDP can be divided into 3 different elements. These elements include contribution to the households' income, net contribution to profits of the local businesses and savings and government tax revenue with values R19 075 billion, R17 963 billion and R17 927 billion respectively. Combined, these elements are equal to the value R55 billion, equivalent to 1.1% of the overall national economy of South Africa. The aforementioned value is 52% higher than the 2013 total value added. The wine industry contribution can be as high as 9% when the wine tourism industry is included (Conradie, 2014). The largest fraction of this amount is generated from wages compensated by the industry and the industry contractors to South African families. Profits for local companies follow and then government tax revenue which signifies the largest value-added constituent directly to the economy.

According to the SAWIS (SAWIS, 2021) January report the GDP effects indicated that the wine industry constitutes a greater share of the entire economic impact. This consists of initial effects, the first-round effects on suppliers, other indirect effects and induced effects at 26.6%, 22.6%, 20.9% and 29.9% sequentially. The direct activities of the wine industry to the GDP have the highest effect.

### 2.4.3 Contribution to government tax revenue

Impact of the wine industry on government tax revenue particularly refers to the government revenue generated from the goods and services tax. This includes the financial profits made from direct and indirect taxes on the production of wine and similar alcoholic products. These are important streams of government revenue. As per SAWIS (2021) estimates, South Africa received government revenue of R17.9 billion from the wine industry indirect taxes. This amount is equivalent to 1.4% of 2018/2019 aggregate government tax revenue. The wine industry contributes more than 50% of its value chain total tax revenue (SAWIS, 2021). This indicates that wine industry has a significant contribution to the South African government revenue, these proceeds are the source of many government spending activities including social grants, education, healthcare and housing (United Nations, 2017). These government activities facilitate the fulfilment of the human rights needs and service delivery to the public.

### 2.4.4 Contribution to employment

The South African wine industry activities sustained 269,096 jobs in the 2019 reporting period, which is equal to 1.6% of the nation's aggregate employment (traditional and casual) (SAWIS, 2021). This consists of the employees directly employed in the wine industry (both agricultural and industrial), the indirect employment that is linked to the intermediary suppliers to wine making. Also, employment arising from other industries and sectors that contribute to the manufacturing and trade of wine yields. The wine industry may only employ 80,173 direct employees, but the influence on job creation in the wider economy is substantial (SAWIS, 2021). Table 2.2 below presents the share of employment creation estimates in different industries as influenced by the wine industry in 2019.

**Table 2.2: Wine industry employment impact on other sectors in the economy (2019)**

| Sector | Jobs created |
|---|---|
| Financial and business services sector | 51,655 |
| Personal, community and social services | 25,892 |
| Wholesale and retail trade sectors | 25,550 |
| Agriculture, forestry and fishing industry | 79,083 |

*Sources: data obtained from (SAWIS, 2021) report.*

As depicted in Table 2.2 above the agriculture, forestry and fishing industries benefit most with 79,083 jobs created in these industries. Followed by the financial and business services sector which likewise largely benefit from the wine industry operations through the creation of 51,655 jobs. However, the wine industry has further supported job creation through the public services 25,892 and commercial activities 25,550 sectors respectively. In total, the wine industry contributed an amount of R19.1 billion towards households' income, the beneficiaries include high income households, which receive 57.2% of the total household income, middle income with 32.5% and low income households with 10.3% of the overall household income (SAWIS, 2021).

### 2.4.5 Contribution to capital formation

Capital formation, alternatively called domestic investments, is the wine industry's influence to net capital gain for a given year of enquiry. Included in this value are the capital stocks (equipment, transportation assets and electricity). Both indirect and direct effects of the wine industry are considered. Given that the wine industry operational activities necessitate the use of various capital goods, such as machinery, equipment, transport, manufacturing and distribution centers (SAWIS, 2021). The capital value needed by the industry to carry out the manufacturing activities and supply of wine goods in South Africa was R98.1 billion in 2019 with R4.1 billion as a direct contribution by the wine industry (SAWIS, 2021). This equals to 0.8% of the overall fixed capital stock needed for economic activity in South Africa. Sectors that receive the most significant investment gains include financial and business services, transport, communication, other services such as water and electricity, manufacturing and wholesale and retail.

### 2.4.6 Contribution to balance of payments

The domestic wine industry has significantly improved its export share with 153% growth rate in value, for the period 2005 to 2019 (Lubinga et al., 2020). Preceding this period was another pivotal 5-year period from 2000 to 2005, where the nation was recognized as one of the significant contributors in the global wine industry, this marked its exceptional performance (Lubinga et al., 2020). As such, wine exports are South Africa's second largest agrarian export product amounting to roughly 50% of its production with the other 50% contributing to domestic sales (Wine Industry Network, 2020). In fact, with a positive balance of trade, 68% (value) average of wine produced locally is exported to the European nations (Lubinga et al., 2020). Given that South Africa exports

this significant amount of wine, it only imports a minimum amount of wine products, hence the need to consider the balance of payment account's impact on the South African economy. The industry exported goods at a value of R8 457 million, which is 0.7% of the overall national exports for the 2019 reporting period. However, the value of the imported finished wine goods amounted to only 0.06 % of the overall nation imports (SAWIS, 2021).

The 2019 estimates indicated that the favourable effect of the wine industry to South Africa's Balance of Payment account was roughly R8 323 million (exclusive of the import substitution effect) (SAWIS, 2021). This amount jumps to R22 987 million with the inclusion of the import substituting effect. It can be gathered that the imports and exports of wine in the industry result in a positive economic impact (positive trade balance). This amounts to an overall economic impact of R22 191 million which represents 1.7% of aggregate national exports in the 2019 reporting year; the wine imports were 1.1% of aggregate national imports in 2019 with a value of R13 868 million (SAWIS, 2021). On the other hand, the direct and indirect suppliers' economic effects and induced effects of spending by the buyers show a shortfall. SAWIS (2021) indicated that this ratifies the decline in job opportunities throughout the value-chain of wine in comparison to the 2013 values. Given the wine industry's low imports, the overall effects are a trade surplus amounting to R8 323 million, this is particularly significant in the agricultural sector which mainly produces for the local market in comparison to the sectors that supply it. The future looks auspicious for South Africa as the quantity and cost of wine exports are estimated to be greater than 2019 and 2020 figures.

According to Istituto di Servizi per il Mercato Agricolo Alimentare (2017), global wine consumption is expected to significantly increase: in China, Russia and the United States it is expected to increase by 21.6%, 5.1%, and 5.7 respectively. These are among the nations that import wine from South Africa. The expansion of the wine sector indicates the significance of ensuring sustainability in the industry throughout the supply chain.

## 2.5 Wine industry in the Western Cape: A profile

The Western Cape Province is well known for its abundant wine-producing farms in South Africa. Given the substantial amount of wines produced in the Western Cape, the largest share of the local wine trade is established in this part of the nation. This is influenced by its geographical diversity, adjoining spectacular mountain ranges, dominant fertile soil types, the adjacent oceans are very influential on the climate (Wine-searcher, 2018).These factors are incredibly important for the viticulture in the region (Jones, 2007). Currently, there are about 560 wineries with 2700 main winegrowers in the Western Cape. The Wine of Origin Scheme separated the winegrowers into 4 major regions: The Breede River Valley, The Little Karoo, Coastal and Olifants River. A proportion of these wineries are small wineries which are situated in the rural farms and are of great value and impact to the economy of those areas.

The Western Cape wine industry contributes around two-thirds to the national Gross Domestic Product (GDP) of R 11.7 billion of the wine industry, which has a direct impact to the province's macro economy. Roughly R 2.1 billion or 18% of the gross revenue can be accredited to wine tourism activities in the Western Cape (SAWID, 2000; SAWIS, 2001).

In the early 2000s the Western Cape Province had about 11% of its working population working in the extensive area of wine tourism (SAWID, 2000). In 2019 about 14% of the Western Cape working population (2.53 million) was employed in the Cape Winelands alone (Cape Winelands District Municipality, 2019). This constitutes of 355 000 jobs in the region. In contrast, at present over 90% of the vineyards and the supplementary wine industry are located in the Western Cape (Demhardt, 2003). Therefore, wine industry in the Western Cape is one of the strongest pillars of the province's economy.

According to Bruwer (2003) the nation's wine industry is among the few industries that are largely situated in the non-metropolitan areas, as such has a crucial impact in regional development, job creation, business investment, business advancement and tourism.

## 2.6 Wine Tourism

### 2.6.1 Background and significance of wine tourism

Wine tourism is perceived as a specialized market in the tourism industry (Montella 2017; Gómez et al., 2018). Its products do not only involve wine, it further comprises of the food and arts and culture. While wine production focuses on the value-chain of agro-activity from viticulture, wine tourism focuses on the consumption of the final product by consumers (Booyens, 2020). These two are essentially found on the opposing sides of the wine industry continuum. Therefore, wine tourism is branching out from farming into tourism. As such, the process from grape farming to consumption by tourists contributes to the economy of the wine sector, resulting to a remarkable impact in regional economies (Ferreira & Hunter, 2017). Therefore wine tourism is a strategic initiative by the wineries to diversify their streams of income and not only rely on agriculture (Doloreux & Lord-Tarte, 2014). Wine tourism is also considered as a stimulator of 'novelty and the improvements of wine regions vitality' (Cambourne et al., 2000). A further research observation has indicated that wineries have become greatly valued in the local economies as a major sources of wages, salaries and employment (Bonn et al., 2018).

### 2.6.2 The economic value of South Africa's wine tourism industry

The cultural practice combined with Cape viticulture have proliferated into the one of the four major attractions for global tourists with respect to South Africa (Alant & Bruwer, 2004; Demhardt, 2003; Grant Thornton Kessel Feinstein, 2003; Tassiopoulos et al., 2004). Currently, there are 29 credible and effective wine-route associations in South Africa. South Africa is among the strongest and audacious promoters of preaching the wine tourism gospel and aiding the promotion of its premium wines in serene settings (Ferreira & Muller, 2013; Rogerson, 2007).

Authors such as Winkler (2013) believe that wine industry tourism is more advanced in South Africa than any in other nation, where the majority of wineries have exceptional tasting amenities, excellent restaurants with astounding vineyard sceneries in the mountains offering exceptional wildlife game and seafood menus. Wine tourism plays a significant role in depicting South Africa internationally as an attractive destination.

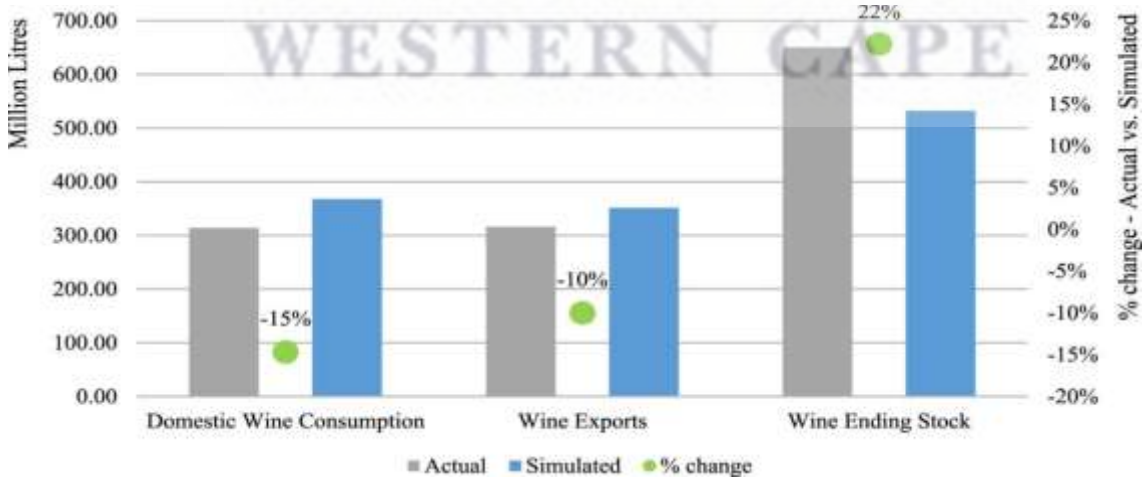
Wine tourism is a branch of the South African tourism industry. Extrapolations from the survey sample by VinPro (2020) indicated that the direct expenditure resulting from the wine tourism industry amounted to R2.4 billion in 2019. As such the overall impact (including direct, indirect and induced) of the wine tourism to the South African GDP was estimated at R7.2 billion in 2019.

VinPro (2020) estimates further indicated that 5 809 permanent employees were employed by the cellars that crush grapes for tourism related activities. A total of 4 414 informal employees were added during the critical period and 2 655 off season. Overall, the wine tourism industry created 36 406 job opportunities (direct, indirect and induced) to the South African economy in 2019.

## 2.7 Wine industry during the period of the COVID-19 epidemic

South Africa has experienced manifold COVID-19 infection waves starting from March 2020. The government introduced procedures to curb the upsurge of the virus. The measures included the introduction of different levels of enforced economic restraints. Such regulations included erratic prohibitions on sales of alcoholic beverages. This had significant ramifications on the wine sector. As such, SAWIS (2021) reported a decline in both domestic sales and exports resulting from the regulations put in place to curtail the spread of the pandemic in 2020. Effects of COVID-19 pandemic sales restrictions on the wine industry are further indicated below in Figure 2.3, with the actual and simulated impacts SAWIS (2021).

**Figure 2.3: Impact of sales ban on domestic consumption, exports and ending stock (2020)**




*Source: David et al., (2021)*

Figure 2.3 presents the comparison of the results from a simulation performed by David, Vink and Cloete (2021) the actual wine volumes in 2020 as reported by SAWIS (2021). Simulated results suggested that there was a 15% drop in domestic sales, this is equivalent to 54 million litres less sales of wine attributed the regulations on sales. That national sales were prohibited for a period 14 weeks throughout 2020, suggests that sales lost during the embargos period were then partially recovered when the ban was lifted. This recovery was enough to restore the wine industry to its levels prior to the epidemic. The harm is equivalent to R410 million loss in revenues related to the principal value only before value added at the retail price.

The impact on exports was a decline of 10% which is equivalent to a loss of 35 million litres of sales resulting from the national sales ban. The curtailments on the international trade were held for a 3-week period in total. The sales ban on exports and the sporadic implementation of the COVID-19 regulations deteriorated the status of the South African wine industry. The industry has been well known for its excellent wine quality and the export of such wines. Failure to distribute purchases settled prior to lockdown risked delisting and loss of shelf space. Under normal circumstances, where free trade is permitted, the simulation results in Figure 2.3 above indicate that the possible increment could have been kept at 18% per annum. Eventually, actual closing stocks were 22% surplus compared to the simulated value. This infers that the trade restrictions enacted in 2020 will have lasting repercussion on the industry.

The reduction in sales resulted in significant increase in stock levels in 2020, closing with an annual stock of 44% higher (SAWIS, 2021). An annual increase would be anticipated even with no sales ban, due to the poor economic atmosphere and its effect on the consumer buying power nationally and internationally.

COVID-19 regulations were not only limited to trade restrictions, the ban on travelling also brought the tourism industry to a stand-still during this time. The loss in the wine tourism income was estimated to be higher than R2.5 billion for the period March to July 2020 with a larger portion of the losses experienced at the tasting room (VinPro, 2020). Given the substantial losses suffered by the industry the South African economy suffered great losses.

## 2.8 Conclusion

Since the early years of the South African wine industry, the industry has pursued a high standard of quality wine production by maintaining regulations in the market. As such the wine industry has successfully and progressively represented and established itself both in the local and international markets. Through observing the macroeconomic components such as GDP, employment and balance of payment, it can be established that wine industry is one of the strongest pillars not only to the Western Cape economy but to the South African economy at large. Differently put, it is evident that the wine industry in the Western Cape does not merely represent a sizeable portion of the nation's agricultural sector, it is well established in the overall economy and has a substantive impact on other economic sectors of the country. The wine industry has expanded and diversified the streams of income largely through the tourism industry and has established one of the most distinct tourist' attractions in the form of wine estates. Therefore, the wine industry impact on the overall economy spills over to every industry involved in the wine value chain from manufacturing sector through to the tourism industry. Needless to say, this industry is among the industries that determine the nation's economic performance.

# CHAPTER 3: IMPORTANCE OF WATER RESOURCES & WASTEWATER MANAGEMENT PRACTICES IN THE WINE INDUSTRY

## 3.1 Introduction

A plethora of studies in the field of wastewater treatment methods in the wine industry have been conducted, where various innovative technologies have been tested in mitigating the winery effluent problem. Despite these efforts, excessive water consumption and wastewater production remain severe drawbacks in the wine industry, which calls for unique, innovative measures. These measures necessitate the consideration of novel technologies whereby the pollutants of the effluent are specified. This chapter discusses the significance of water in the wine industry, procedures of effluent management and discharge and the importance of wastewater treatment plants for effluent treatment and recovery.

## 3.2 Importance of water in the wine industry

Water is a critical resource in the manufacturing of wine. The importance of water cannot be stressed enough, particularly in the face of the prevalent global climate change challenges and anticipated droughts in the vine-growing areas. Water resources are crucial for sustainability in viticulture as the production of grapes, its quality and economic feasibility mainly rely on the availability water (Mirás-Avalos & Araujo, 2021). Regarding agricultural products, wine production is the most dependent on freshwater use; for instance, 500 to 600 litres of water are required to make one litre of wine (Bujdosó & Waltner, 2017). Vine-growing-dependent wineries are generally more water-intensive as water is consumed for irrigation during the grape-growing stages and in the winemaking process. In general, the aggregate water consumption of vineyards ranges between 300 and 700 mm and is greater than the yearly average precipitation in various vinicultural regions, which is perilous for vineyard sustainability (Medrano et al., 2015). For instance, irrigation is the main water consumption activity in South Africa during grape growing.

Irrigation is essential in the grape growing process to supply water for crop growth and evapotranspiration (ET) needs of the vine, mainly when the water supply from rainfall and present soil moisture is insufficient (Wines Australia, n.d). Different irrigation factors that facilitate water resource conservation and sustainability require consideration. These include irrigation system, soil type, crop growth stage, vine health, amount and quality of water, irrigation and limitation of soil vaporisation, which should be considered in water resource management, mainly when there is limited water supply (Wines Australia, n.d).

### 3.2.1 Importance of water for irrigation

Globally, crop irrigation is a significant freshwater consumption activity. With the growing global water scarcity and stricter agricultural and wine industry regulations, more efficient irrigation strategies are required (Adeyemi et al., 2017). Water used for irrigation amounts to 70% of global freshwater consumption, indicating that irrigation is the primary source of freshwater consumptive water (World Bank, 2020). In fact, in developing nations, the freshwater withdrawals that provide irrigation are more significant than 80% of total consumption (Hedley et al., 2014). Agricultural irrigation is used on roughly 20% of the overall nurtured land and supports 40% of the global food supply (Martínez-Alvarez et al., 2018). Irrigation supports 25-30% of the South African agricultural production. Irrigation was also projected to produce 90% of crops that yield high returns, including fruits (Bonthuys, 2018).

By definition, irrigation is watering plants, pastures and crops through water use, generally delivered through pumps, pipes, sprinklers, canals and other efficient methods (Conserve Energy Future, n.d). Put differently, it is an innovative system used to help plants grow due to rainfall uncertainties. Lack or absence of irrigation or rainfall in the vineyards may result in plant failure and undersupply of grapes. Not only does irrigation facilitate plant growth by providing the water required, but it is also instrumental in supporting plants with the necessary nutrients in growth stages to achieve the best harvest (Conserve Energy Future, n.d). While irrigated land results in higher crop yields compared to land crop yields that solely rely on rainfall, both methods require a measurable amount of water consumption (Olayide et al., 2016). Water requirements vary for

different vines and zones within the vineyard based on temperatures, vines' composition, and other factors.

The composition quality of wine grapes for making wine is reliant on the background of vine water conditions through the growth stages (Bellvert, 2016). Monitoring vine water conditions during the season is required to employ the most applicable irrigation approach for each cultivar (Basile, 2011). Vine water status and the soil moisture, therefore, determine the water required for irrigation. When determining the required water supply, sustainable water practices should be observed, particularly in semi-arid regions, while not compromising the quality of the crop and its harvest. Therefore, water use efficiency ought to be maximised. However, such efficiency maximisation may be insignificant without measured estimates of groundwater use. Available water from groundwater basins varies from one vineyard to another. Efficiency maximisation generally sustains the irrigated agricultural economy presently led by wine grape production (Battany & Tindula, 2018).

The water supply for irrigation is equally important concerning water management practices. Water use efficiency and water management practices facilitate sustainability in the wine industry. Among other irrigation methods, precision irrigation is deemed one method that considers the environmental impacts (Ozdemir et al., 2017). Precision irrigation seeks to provide crop water accurately, timeously, and spatially uniformly (Adeyemi et al., 2017). The literature also reveals that precision irrigation can be a beneficial method to accomplish ecological goals related to sustainability (Adeyemi, 2017; Ozdemir et al., 2017; and Sarma, 2016). Intensifying vineyard water use efficiency (WUE) is thus vital for sustainability in the viticulture-based industry, particularly in regions with undesirably low precipitation levels.

In addition, improved water-resources sustainability in vineyards can be accomplished through agro technology and cultivated variety selection (Medriano et al., 2015). Agronomical innovations are centered on expanding water storage capacity of the soil while decreasing soil water losses (Medriano et al., 2015). Good practices in water management of vineyards must include avoiding excessive water consumption during crop irrigation.

**Annual water requirements for grape growing**

The quantity of water essential to grow grapes for different types of wine can vary significantly. Generally, white grapes require more water than red grape varieties. According to a study by Williams (2014), grapevine water requirements range between 300 and 600 mm in moderate temperatures, while the range in areas with higher (hot) temperatures is between 400 and 800 mm in the growing period.

Vine water needs may also depend on whether the vine is rain-fed or irrigated. These two methods are the most adopted for vine cultivation depending on the region and weather conditions. For instance, in the European winegrowing districts, vineyards are largely cultivated through rain-fed methods (Rienth & Scholasch, 2019), while most South African vineyards require irrigation methods to achieve sustainable growth, desired harvest and vine quality; apart from some rain-fed vineyards in the coastline area of the Western Cape region (Myburgh, 2016). The rain-fed method, which some South African vineyards rely on, is also known as the "dry farming" method and is a strategic move towards inducing the minimal potential surface water (Rienth & Scholasch, 2019). The subject of rain-fed vineyards is not necessarily a topic of interest in this study. Conversely, irrigation is the most reliable and instrumental method, mainly due to the recent dry seasons and the anticipated droughts. Therefore, the sustainability of water resources is at the heart of the viticulture industry; thus, it is in the best interest of every vine grower.

### 3.2.2 Importance of water for wine production

Water is a significant input in the winemaking process; it serves various functions during production. It is also used for cleaning, sanitising, and as a supplement to prepare additions (Savits, 2021). The clean water used in wine production is usually extracted from the municipal water reticulation systems and sometimes from wells in rural districts. Clean water required in the winemaking process is that of drinking water quality standards. Meanwhile, water quality of other standards is required for use in other parts of the production process (Savits, 2021).

In addition, winemaking requires large volumes of water. Arjen Hoekstra at the Water Footprint Network has determined that to make a 125 millilitre (ml) glass of wine, 100 to 200 litres (l) of

water is required (Thomas, 2018). The production also often happens in low rainfall areas with long dry seasons and often susceptible to drought. For instance, the Western Cape region of the South African wine industry nearly had a "day zero" situation with the city's dams nearly dry (Lakaje, 2022). Also, California's wine country was hit by a five-year drought ending in 2017. Many other wine-producing regions were confronted by the drought that lasted for five years until 2017 and caused a severe impact on the wine industry. Meanwhile, producing one litre of wine requires 400 to 600 litres of water (Bujdosó & Waltner, 2017). As a result, water saving and sustainability have become extremely crucial in such a water-reliant industry (Thomas, 2018).

The growing water shortages from climate change negatively affect the grape harvest and limit the profitability and sustainability of wine production (van Leeuwen et al., 2019). As a result, drought resistance strategies are gradually becoming appropriate worldwide, particularly under increasingly dry circumstances (van Leeuwen et al., 2019).

### 3.2.3 Importance of water-saving practices in relation to wastewater in the wine industry

According to Lee and Okos (2011), all wineries should make it their objective to minimise winery wastewater. Lee and Okos (2011) use the concept of a 'zero discharge process' to emphasise the importance of wastewater minimisation. The zero discharge process concept describes scaling down a sizeable quantity of water and energy consumed in the production process and eventually producing waste-free food and beverages (Conradie et al., 2014). One of the wastewater management systems designed to achieve low levels of wastewater is the zero-liquid discharge (ZLD) system. ZLD is a wastewater management method that guarantees zero industrial wastewater is discharged into the environment (Amutha, 2017). Its wastewater treatment process involves recycling, recovery and reuse for commercial purposes. This process reclaims salts and other chemical compounds, and thus, it lays a foundation for economic benefits (Amutha, 2017). This process involves high costs, which is its main limitation.

Furthermore, using water sparingly reduces the costs associated with fresh water use and decreases the relevant costs associated with wastewater treatment (Fillaudeau et al., 2008, cited by Conradie et al., 2014). Therefore, the lesser the quantity of water utilised in the production of wine, the lesser the freshwater costs incurred and, subsequently, the lesser the wastewater treatment costs.

## 3.3 Characteristics of winery wastewater and its impact on the environment

Studies in the area of wastewater management, treatment and reuse has seen an exponential rise in the academic literature in the past few years. Studies have significantly engaged in technological interventions by applying theoretical and practical measures. In water scarcity, wastewater from the municipalities is the conventional kind of wastewater categorised as low-strength waste streams (Sikosana et al., 2019). It is categorised by its dissolved biological content and high suspended organic matter content (Sikosana et al., 2019). Although the issue of wastewater management has been studied in South Africa to some extent, due to the large number of winery effluent more attention is needed in the area of wastewater management in the wine industry.

According to South African law (Government Gazette, 2001), winery effluent is decomposable industrial wastewater. Consequently, it consists of five parameters, which are chemical oxygen demand (COD), pH, electrical conductivity (EC), sodium adsorption ratio (SAR) and faecal coliforms.

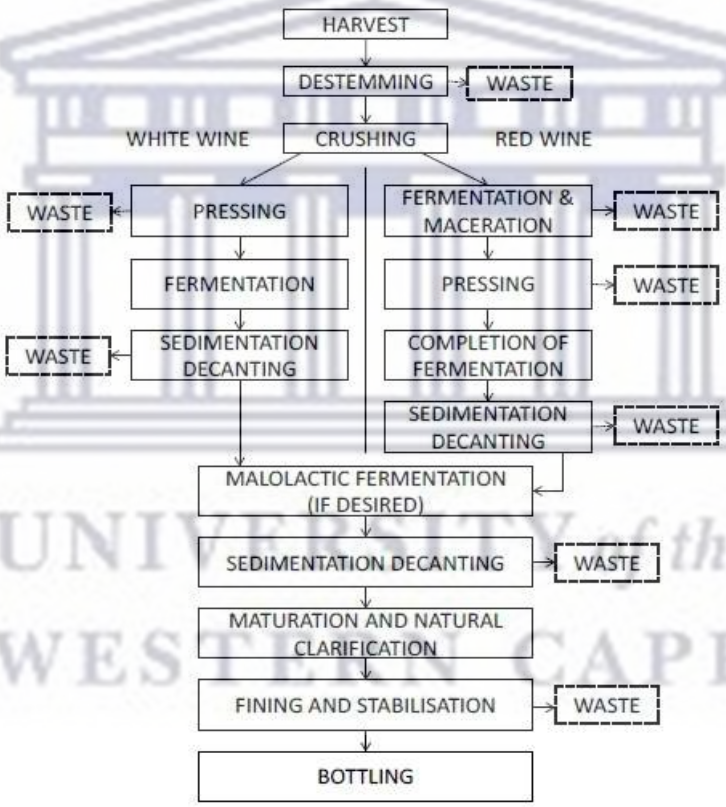
Wastewater treatment plants are prospective net renewable energy producers, translating the chemically suppressed energy content in the organic toxins of blue municipal wastewater to an expedient energy hauler while generating potable water for communities (Sikosana et al., 2019). Therefore, the municipalities are essentially the primary source of water supply to different communities, and their wastewater treatment carries potential additional benefits such as energy production. On the other hand, wineries do not only use fresh water for their supply chain purposes but also for indirect uses of water, such as water used for cleaning (Sikosana et al., 2019). As such, the use of freshwater in the wine production process is incredibly important. However, according to Howell and Myburgh (2018), about 50% of the freshwater used by some wineries result in wastewater. This wastewater generated from the wineries in turn poses serious environmental and social effects which is cause for concern.

### 3.3.1 Production and composition of wastewater

Wastewater in the winery is generated mainly from cleaning processes throughout the various stages of wine production (Mulidzi, 2007). When considering the amount of wastewater the

wineries produce, it is essential to understand the winemaking process. Wine production processes include crushing and fermentation of grapes, filtering grape skins and seeds, and then storing, clarifying and maturing young wines (Mulidzi, 2016). Figure 3.1 below depicts a methodical diagram of the main stages of wine production and distinctly shows where waste is generated in the process. The waste generated through the first stage stem removal is parted from the water. As a result, it is one phase that does not add directly to the chemical oxygen demand (COD) in the raw wastewater (Woodard & Curran, 2006).

**Figure 3.1: Layout of waste generated in the winemaking process of red and white**




*Source: (adapted from Arvanitoyannis et al., 2006; Devesa-Rey et al., 2011; Conradie, et al., 2014)*

The amount of wastewater generated from wineries vastly differs from one winery to another. Various factors need to be considered in the treatment of the winery effluent, including where the winery is located and the composition of wastewater. Winery wastewater contains large amounts of compounds of components consisting of potassium (K), sodium (Na) and phosphorous (P), which may cause pollution in the neighboring environment, particularly if the wastewater is not appropriately treated (Sheridan et al., 2011; Conradie et al., 2014). Although the formation of

wastewater may be unique for each winery, chemical oxygen demand (COD), pH and sodium adsorption ratio (SAR) are among the critical parameters of wastewater (Howell, 2016). In South Africa, seasonal factors substantially impacted the amount of wastewater generated (Howell & Myburgh, 2018). Wastewater may also contain large amounts of organic content, low pH, and varying saltiness and nutritious extent. All these factors show that the wastewaters possess the capacity to harm the environmental (Mosse et al., 2011; Laurenson et al., 2012).

Large volumes of effluent are also generated by cleaning winery equipment with water. Table 3.1 below depicts the impacts of wastewater on effluent quantity and quality, impacting the legal parameters of quality.

**Table 3.1: Winery actions related to winery wastewater quality and quantity and the impact on the quality parameters**

| Winery action | Impact on wastewater quantity | Impact on wastewater quality | Impact on legal wastewater parameters |
|---|---|---|---|
| **Cleaning water** | | | |
| Alkali washing and neutralisation | Up to 33% | Increase in NA, K, COD and pH | Increase in EC, AR, COD, variation in pH |
| Rinse water (tanks, floors, transfer lines, bottles, barrels, etc.) | Up to 43% | Increase in NA, P, CI, COD | Increase in EC, AR, COD, variation in pH |
| **Process water** | | | |
| Filtration with filter aid | Up to 15% | Various contaminants | Increase in COD and EC, decrease in pH |
| Acidification and stabilisation of wine | Up to 3% | $H_2SO_4$ or $N_aCI$ | Increase in COD and EC, decrease in pH |
| Cooling tower waste | Up to 6% | Various salts | Increase in COD and EC |
| **Other sources** | | | |
| Laboratory practices | Up to 5-10% | Various salts, variation in pH, etc. | Increase in COD and EC |

EC - Electrical conductivity, SAR - Sodium Adsorption Rate, COD - Chemical Oxygen Demand

*Source: (Adapted from Van Schoor 2005; Conradie et al., 2014)*

There are two types winery effluent discharge, the solid and liquid waste. Solid waste is mainly produced during the grape gathering process, while liquid waste is produced in the winemaking process (Howell & Myburgh, 2018). Solid winery effluence: grape stem, pomace, and grape seeds differ in chemical composition and quality. Quantitatively, it comprises a maximum of 7.5 %, 45

% and 6 % for grape stalks, pomace and grape seeds, correspondingly (Zacharof, 2017). Grape stalks are the main component of winery solid waste, with a regular production of roughly 5 tonnes per hectare per annum (Leiva et al., 2014). They have high lignin, cellulose (N), and potassium (K), are highly valued in agriculture, and thus are utilised for composting (Begalli et al., 2009). Due to the grape stalks low organic matter content, they are incredibly effective for soils. Besides having high suspended solids content (mostly grape skins and pips), winery wastewaters generally have high biological oxygen demand (BOD) and chemical oxygen demand (COD). This effluent grew concurrently with environmental regulations, with which some small wineries strive to comply.

### 3.3.2 Environment effects of the winery wastewater

Most winegrowers in South Africa discharge their effluent by watering the pastures in grazing corrals (Zingelwa & Wooldridge, 2010). Discharging effluent directly to land was recognised as the efficient and valuable discharge system for all winery waste waters, nutrients and organic matter contents (Ryder, 1995). A survey undertaken by Sheridan et al. (2005) revealed that 60% of the South African wineries discharge their wastewater by crop watering, release 10% into municipal sewers, another 10% is vaporised, 7% treat their waste with French drains, while storage dams, wastewater treatment plants, river discharge, or other, unstipulated methods treat the residual 10% of wastewater. At the point of wastewater discharge, each winery's water quality differs. Thus, the environmental impacts vary depending on the contamination levels assessed by the level of COD and pH and the treated wastewater disposal method (Howell & Myburgh, 2018).

Wine production involves high volumes of solid waste, including grape seeds, skins and stalks (grape pomace). When these are disposed to the environment in their organic state, they pose some environmental threats (foul odours and groundwater pollution) (Arvanitoyannis et al., 2006). Festering grape pomace creates a conducive environment for flies and pests to thrive (Conradie et al., 2014). Pomace leachate comprises chemical compounds that penetrate the exterior soil and groundwater, reducing oxygen (Arvanitoyannis et al., 2006).

Winery wastewater land application increases the soil pH, which results in the augmented dissolution of organic material, which can encourage soil dispersion (Faisal Anwar, 2011). A pH above and below the legally required pH poses harm to macro- and micro-organisms and solubility

metals with high densities (Mulidzi, 2016). It also results in the death of aquatic animals. Similarly, extreme levels of BOC and COD result in the death of fish and the like due to low oxygen levels and odours generated by anaerobic decomposition (Kumar & Christen, 2009). Effects on nutrients (N, P, K) and drinking water supply with nitrate (N) may harm children. Salinity (EC, TDS) transmits unwanted taste to water, which is unhealthy for plants and animals (South Australian EPA, 2004). Sodicity (SAR) degenerates the soil structure and is hazardous to plants. Finally, Solids (TSS) can diminish light diffusion in water, posing a health threat to the biodiversity and stenches generated by anaerobic decomposition (Conrad et al., 2014). Knowledge of the winery wastewater effects is vital in helping establish and advance the winery wastewater treatment methods (Devesa-Rey et al., 2011)

## 3.4 Procedures and practices of wastewater management

### 3.4.1 Wastewater legal requirements and compliance standards in South Africa

An upsurge in winemaking and the stringent environmental rules in South Africa calls for high demand to regulate and manage winery wastewater sustainably.

South African environmental legislation prohibits the release of unprocessed winery effluent into regular water sources, this has compelled wine producers to control their effluent responsively (Schoor, 2001). For over a decade, the South African wine industry has subsidised studies in sustainable management and treatment of winery effluent (Mulidzi, 2005).

Mulidzi et al. (2009) conducted a study on the formation of wastewater from wineries in the Western and Northern Cape. The findings suggested that all ten participating wineries were noncompliant with obligatory environmental guidelines for the sampling duration. In fact, according to the Department of Water Affairs General Authorisations (2013), the majority of local wineries struggled to meet the set effluent legal requirements to emit their organic wastewater into regular water resources. Mulidzi (2016) further emphasised the matter, indicating that South African regulation necessitates that wine storages implement wastewater inspection measures, because they do not have historical documentation of the standard and measure of the effluent. Verily, keeping track of wastewater's influence on aquatic resources, groundwater, land and vegetation should be obligatory (Van Schoor & Rossouw, 2004).

Findings from a research project by Rodda et al. (2011) revealed that local governmental authorities put in place policies on sustainable practices of greywater use as an optional water resource for irrigating small farms. On the other hand, South African guidelines in irrigation for agrarian water consumption demand that an SAR be below 2 to circumvent the development of sodium toxicity in plants that are reactive to sodium and an EL below 20 mS/m to safeguard an acceptable infiltration rate. The Department of Water Affairs and Forestry (DWAF) (1996) recommends a pH ranging from 6.5 to 8.4 for agricultural irrigation water. Table 3.2 below shows the legal limits of water quality standards legislated by the (Department of Water Affairs, 2013).

**Table 3.2: General Authorizations for legislated limits for irrigation water quality in South Africa**

| | Maximum irrigation volume allowed ($m^3$/day) | | |
|---|---|---|---|
| Parameter | <50 | <500 | <2 000 |
| pH | 6 - 9 | 6 - 9 | 5.5 – 9.5 |
| Faecal coliforms (per 100 mL) | 1 000 000 | 100 000 | 1 000 |
| COD (mg/L) | 5 000 | 400 | 75 |
| EC (mS/m) | 200 | 200 | 70 – 150 |
| SS (mg/L) | 1 000 | - | <25 |
| SAR | <5 | <5 | <5 |

Chemical Oxygen Demand (COD); Electrical Conductivity (EC); Suspended Solids (SS); Sodium Adsorption Ratio (SAR). *Source: (Department of Water Affairs, 2013)*

### 3.4.2 Importance of wastewater management and the use of innovative WWTPs

Wastewater treatment is essential for environmental sustainability and human health protection (Molinos-Senante et al., 2016). Additionally, water officials have a certain amount of money set aside for this purpose; therefore, increasing the effectiveness of WWTPs is essential for long-term economic viability (Beltrao et al., 2009; Gossling et al., 2012). According to logic, scientists focus on enhancing effluent quality primarily by lowering the amount of contaminants disposed into the environs (Hernández-Sancho et al., 2011; Lazarova et al., 2012). Also, scientists have concentrated on lowering the procedure's costs, mostly related to the inputs utilised in the purification practices (Piao et al., 2016). In this instance, the Water Framework Directive established by the European

Union stipulates that the whole cost of water services must be recovered, which implies that the expenses associated with running WWTPs must be included in consumer bills.

Treated winery wastewater is required to meet specific environmental standards and requirements to be appropriate for use**.** However, small wineries currently struggle with water discharge and reuse processes that are environmentally friendly and cost-effective (Litaor et al., 2015). Although water purification and reuse is an old concept, it has become imperative in the wine industry due to the growing number of wineries and wine production. Unfortunately, wineries, particularly small-footprint wineries, struggle with the high costs incurred in the waste treatment process. From this perspective, technological innovations and unconventional procedures are evolving to substitute the orthodox procedures and recuperate bioactive chemicals from grape pomace to encourage "greener" technologies, given that the removal is the most significant post-processing step (Kalli et al., 2018).

The initiation of innovative technologies has prospects of easing methodological mistakes in water-use estimations, collecting field-level data, measuring water consumption in viticulture with accuracy, deducing information about the water footprint of the winemaking and formulating rigorous marketing strategies to interact better with consumers (Van De Laan et al., 2019).

### 3.4.3 Wastewater Treatment Processes

The majority of wastewater treatment operations include a minimum of one physicochemical (consisting of sedimentation, coagulation, flocculation, filtration, reverse osmosis, and electrocoagulation) step, which is fundamental to eliminating large solids found in the effluent (Mehmood et al., 2019). This elementary step is straightforward, operative, and valuable to avoid clogging preliminary on biological treatment equipment with solids, like seeds, stocks, and leaves (Mosse et al., 2011). This primary treatment stage includes using screens to remove large substances.

Preliminary physicochemical treatment has been utilised mainly as pre-treatment to eliminate organic load liquids of winery wastewater clouded with sediment before the biological treatment (Mehmood et al., 2019). Other benefits of physicochemical treatment systems include eliminating sludge growth and erosion on treatment pumps, enriching treatment effectiveness by adding chemical substances and improving water quality appropriate for disposal (Mosse et al., 2011).

Primary treatment methods are essential and valuable for removing fine particles of sediment in the winery wastewater before the semi-treated effluent is transmitted to biological treatment methods.

Winery wastewater generally has acid, with a pH of less than 3 (Conradie et al., 2014). The water treatment process includes adding lime to the water to give a rise the low pH to the legally permitted level and that of the irrigated crop requirement (Van Schoor, 2005). Then, the water is pumped to sedimentation or maturation pools to allow the remaining solids to settle. Conditional to the wastewater quality, the water can be used for irrigation purposes on specific crops, such as lawn and pasture grass, in specific soils (Van Schoor, 2005). Another step may be circulating and ventilating the effluent in dams using an oxygenate pump method. If these stages are managed precisely, wastewater treatment can be reasonably effective, mostly in reducing COD levels (Conradie et al., 2014).

**The proposed Shear Separation Floatation (SSF) wastewater treatment method at Winery X**

A Shear Separation Floatation (SSF) technology is the proposed novel and superior technology in this study to treat the effluent at Winery X. Shear separation and floatation (SSF) is a cutting-edge water treatment technology by floatation, initially installed by Pieter Jansen, CEO of Abrimix, South Africa. Flotation is one of the most exceptional separation methods, which joins three stages: Gas phase, liquid phase, and solid phase (separately) (Kyzas & Matis, 2019). It originates from mineral processing, known as "froth flotation". The resistance of the lighter flocks is used to drive the separation of particulate material from the processed water. Flotation is appropriate for the microfiltration pre-treatment phase; ceramic flat-sheet membrane modules of multi-channel geometry are applied (Kyzas & Matis, 2019). With its various methods, flotation is recognized as an effective separation process, helping to recover different materials and, hence, recycling. The SSF technology adds hydrodynamic shear as a vital characteristic of the flotation technology and is believed to enhance the productivity of the separation process.

A diagram of the SSF plant operation installed at Winery X is demonstrated in Appendix E. The first step includes the organisation of the winery effluent to adjust pH to suit the hydrated lime. Then, coagulant and pressurised air are added to the alkalised wastewater before the discharge goes into the Abrimix licenced inline mixer. The mixer safeguards hydrodynamic shear mixing to

generate standardised charge-neutral particulates blended with air bubbles. Then, the mixture goes out of the mixer and is blended with flocculants to determine the development of large flocs. Next, the wastewater goes into a floatation tank, where air bubbles and large flocs interplay and levitate to the upper part of the tank to be discharged as froth, resulting in a decreased total suspended solids (TSS) content.

## 3.5 Conclusion

This chapter discussed the significance of water in the wineries and the importance of wastewater treatment. Discussions above highlight water as the main asset in the wine industry, from the grape growing stages to the wastewater cleaning process. Water is the most significant input in the winemaking process. As such, water management and the reduction of wastewater should be maximised. Also, improving the quality of WWTPs used for wastewater treatment is essential to produce better results in water purification and to determine the types of pollutants involved and their costs. Lastly, implementing novel technologies (WWTPs) is crucial to keep up with set environmental standards in the wineries.

# CHAPTER 4: LITERATURE REVIEW

## 4.1 Introduction

This chapter consists of the literature for this study by examining the historical developments of economic and cost-benefit analysis and their theoretical underpinnings. Firstly, the fundamental concepts of the study are defined, and then the evolution of the economic analysis and cost-benefit analysis are discussed. It further examines the empirical literature on economic analysis and cost-benefit analysis in assessing the viability of private projects in general and wastewater treatment technologies in particular.

## 4.2 Definition of concepts

### 4.2.1 Economic Analysis (EA)

Economic analysis embraces the process of analysing various aspects associated with the economic viability of a project. It is a broad concept applied in different fields for different projects, both in the public and private sectors. These projects comprise but are not limited to energy supply projects, environmental projects, water resources projects, environmental policy, education and health-related projects (Jain & Singh, 2003; Norbert, 2018; Wellington, 2018). Economic analysis of projects helps identify and pick civic investments that will sustainably better the welfare of recipients and a region (Asian Development Bank, 2013). It is synchronised with institutional, financial, environmental, social and poverty research, which forms a vital part of investment evaluation.

According to the Asian Development Bank (2018), economic analysis is critical in guiding decision-makers on the significance of proceeding with an investment project to boost environmental value. It is also helpful to decide how far to go to avoid possible environmental harm from investment projects not primarily intended for environmental purposes (Asian Development Bank, 2007). Put differently, economic analysis involves an obligation to optimise the cumulative recognition of preference fulfilment for society at large (Wellington, 2018). This definition aligns with the relatively specific meaning of efficiency in economic theory. Efficiency, in the conventional meaning of the term, speaks to the production of a preferred outcome with the

least effort, expense, or waste (Petrou, 2014). However, efficiency in economic theory refers to an optimal allocation of every resource to the extent that every single person is served in the most preferred and satisfactory manner while keeping inefficiency and waste levels low (Economic Efficiency: Definition & Examples, 2016).

### 4.2.2 Cost-benefit Analysis (CBA)

Cost-benefit Analysis (CBA) is a method of economic valuation that studies the economic costs and benefits of a given program through the comparison of the discounted flows of costs and benefits within a particular timeframe (Dixon, 2012). Costs and benefits acknowledged are calculated in a specific currency to enable direct comparison (Ingle, 2014). These benefits and costs are then averaged across all members of the defined community (Pearce, 1983). Data analysed must include timeframe, values of project costs and benefits for every year involved in the valuation and the discount rate. Given that project expenses and benefits accrue over time, they are discounted to the base year present values (PVs). Discounting considers the public opportunity cost of capital and people's preference for the present over the future (Ingle, 2014). It is indeed a valuable decision-making tool for estimations in cost-benefit expenditure projects; it also caters for environmental and socio-cultural impressions of the initiatives (Bumbescu & Voiculescu, 2014). In economic analysis studies, the CBA is an extensively used tool as it is considered sensible and a methodical decision-making support instrument (Djukic et al., 2016).

### 4.2.3 Cost-effectiveness Analysis (CEA)

Cost-effectiveness is an economic evaluation process which covers independent interventions with and without a budget constraint (Brent, 2023). It is defined as an economic evaluation technique designed to assess the feasibility of a recommended project alongside its value (Henderson, 2010). It outlines the aims of a given project and selects the outcome that reduces the discounted costs of capital for a relative output (Edwards, 2011). However, with CEA, a lower price does not imply high effectiveness, and it only evaluates benefits in physical units rather than monetary terms (Commonwealth of Australia, 2006).

### 4.2.4 Cost-utility analysis (CUA)

Robinson (1993) describes cost-utility analysis as a method of economic valuation whereby the results of other possible courses of action or programmes are portrayed in per utility-based unit of measurement known as the quality-adjusted life year (QALY). QALY is an extensively applied utility-based measure in cost-utility analysis.

## 4.3 Historical foundations of economic analysis and cost-benefit analysis

### 4.3.1 History and development of economic analysis

Economic analysis originated from a book by Joseph A. Schumpeter titled *"History of Economic Analysis"*. Schumpeter's application of *economic analysis* is two-fold: it is initially defined to include history, statistics and theory, and in a more specific sense, it refers to a procedure that proceeds a vision but excludes it (Richardson, 1955). Schumpeter's themes include differences between economics as a science and political economy and differentiate between objective *consultant administrators* as dissimilar mercenary pamphleteers (Perlman, 1983). Economic analysis as science was renowned for having a distinct history, whereas economic philosophy and politics are considered afflictions (Schumpeter, 1954).

The topic of history focuses on economics from a purely analytical or scientific perspective. The command of techniques, which are classified under three heads, history, statistics, and theory"—collectively known as "economic analysis"—is what differentiates the scientific economist from other writers and philosophers on economic matters (Richardson, 1955). Schumpeter relies mainly on analysing scientific guidelines as a method inclined to extinguish faults conditioned by ideologies mechanically. A "science" is described as "tooled knowledge," a subject where unique methods of fact-finding and analysis are produced. Schumpeter proposes to tell the tale of economic thinking, which is scientific in this sense (Richardson, 1955).

Since the first book on economic analysis by Schumpeter (1954), discussions around this topic have emerged. To mention a few, *Types of Economic Theory: From Mercantilism to*

*Institutionalism* by Wesley Clair Mitchell and *A History of Economic Reasoning* by Kari Pribram, although both never synthesised a vision.

Further origins of economic analysis are found in the book *Foundations of Economic Analysis* by Paul A. Samuelson, published in 1947, with a later edition published in 1983 by the Harvard University Press. Samuelson (1947) attempted to reveal a mutual mathematical structure essential to manifold divisions of economics from two fundamental philosophies: 1) maximising behaviour of agents (profit by firms and utility by consumers) and 2) equilibrium steadiness to economic systems (economies or markets) (Harvard University Press, n.d). It further improved the index numbers theory and made welfare economics widely applicable.

### 4.3.2 History and development of cost-benefit analysis

A conventional procedure for decision-making was recounted by Benjamin Franklin (1772) back in the 18th century. He drafted a list of advantages and disadvantages and highlighted those of equal significance. At times, this meant contrasting more advantages against fewer disadvantages and vice versa (Koopmans & Mouter, 2020). After all, the advantages and disadvantages are compared, and the best decision is made. Given this rational decision-making procedure, establishing comparative advantages and disadvantages is essential. There are different methods to achieve that, two of them being cost-effectiveness analysis (CEA) and cost-benefit analysis (CBA). These two economic evaluation measures are economic evaluation instruments that necessitate the recognition, determination, and comparison of all significant costs and anticipated outcomes of the projects (Tolpin, 1988). These two techniques have been extensively applied since the mid-1960s to evaluate healthcare interventions and programs; they later gained popularity and were applied in other disciplines. CBA and CEA are not without limitations; however, despite the limitations these two methods have, their ability and worth to generate information that helps decision-making should not be underrated.

Cost-benefit analysis was mainly coined by Jules Dupuit in the 1840s. Dupuit's extensive and central contribution to economic debates was on willingness-to-pay (WTP) and the consumer surplus (Ingle, 2014). Dupuit also called the willingness-to-pay "relative utility", believing that

what people are willing to pay for is the only utility (Koopmans & Mouter, 2020). On the other hand, consumer surplus the gap between the actual price consumers pay and their desire to pay for a good, provided they pay less than what they are willing to pay and enjoy additional utility (Pettinger, 2018). Dupuilt contended that, although the least advantage of a project is the quantity of the goods produced by the project times the value of the goods, this can be surpassed given that some buyers may be keen to pay a price higher than the asking price, as such enjoy a net welfare gain (Ingle, 2014). He also untaken algebraic examples of how to calculate the costs and benefits of a canal (Koopmans & Mouter, 2020).

The practical application of the CBA in the real world was first seen in the US Flood Control Act of 1936, which legislated a mandatory application of CBA for flood control projects. The guidelines were then issued in 1950. The Act paved the way for establishing the necessary welfare economic fundamentals.

Welfare economics later served as a theoretical basis for CBA. The Act mandated that a flood control project's benefits should surpass its costs despite how often they occur (Pearce, 1998). Although the Act required that all costs be included, it only considered construction costs instead of welfare losses (Pearce, 1983). Post 1960, applying CBA became compulsory in the United Kingdom (UK), the United States of America (USA), and Canada for specific policies and projects. During the mid-1960s, CBA techniques were further applied to a broader range of public spending decisions, which included the first momentous application of CBA in the program planning of the health sector (Tolphin, 1988). In the 1970s, international organisations officially embraced the CBA and established relevant guidelines for it, which were specifically designed for developing nations. Organisation for Economic Co-operation and Development (OECD) guidelines to carry out CBA were drafted by Little and Mirrlees in (1969) and revised in 1974. This event was followed by the publication of guidelines for the United Nations International for Development Organisation (UNIDO) compiled by Marglin, Sen and Dasgupta in 1972. Finally, the World Bank guidelines were prepared by Squire and van der Tak (Pearce, 1983). Currently, most Western nations legally require that CBA be executed for regulatory adjustments, and government organisations have compiled guidelines (Boardman et al., 2018).

Furthermore, a number of textbooks about CBA that apply to developing and developed nations have been produced. For instance, *Cost-benefit Analysis: Concepts and Practice* by Boardman et al. (2018); *Cost-benefit Analysis and the Environment: Recent Developments* by Pearce et al. (2006); *Cost-benefit Analysis* by Layard and Glaister (1994) and *Cost-benefit Analysis: A Survey* by Prest and Turvey (1966) were published. In South Africa, Central Economic Advisory Services (CEAS) first compiled the national guidelines for CBA with the title *Manual for Cost-Benefit Analysis in* 1989 (Ingid, 2014). In 2002, the Conningarth Economists published an amended form of the manual titled *A Manual for Cost-Benefit Analysis in South Africa with Special Reference to Water Resource Development*. In 2007, the Conningarth Economists (2007) published a second edition.

## 4.4 Theoretical Literature of economic analysis

### 4.4.1 Economic analysis (EA)

The greatest challenge confronting different nations, government organisations (agents) or even private sector industries is distributing inherently scarce resources to different activities to maximise the social benefit to the society (Squire, 1975). Given the scarcity of resources, decisions must be made amid competing alternatives, and economic analysis of projects is one way of appraising alternatives appropriately and thoroughly. Preparation of the decision-making on economic viability of executing a specific commercial investment program is centered on a suitable economic justification and a conceivable economic implication (Potashnik et al., 2018). If the conceivable economic implication matches the targeted economic implication (equal or greater than it), the program execution can be deemed economically worthwhile; otherwise, it is not feasible. However, economic analysis is also conducted from an outlook of the entire economy, and it evaluates the national effect of a development on the welfare of the nation's citizens (Asian Development Bank, 2013). Economic analysis includes costs that impose additional burden (Bhattacharyya, 2019).

An example of an economic analysis based on the entire economy is a study conducted by Hahn and Tetlock (2008), which uses economic analysis to make amendments to government regulations in the United States of America. Below is a fundamental equation that reflects the net social net benefits.

**Equation 4.1: The net economic value of an investment**

External benefits to society − External cost to society − CAPEX − OPEX = Net benefits to society

*Source: Edomah, 2018*

The decisions made affect the entire economy and its citizens. Economic analysis should be as simple and inclusive as possible for decision-making. Put differently, although economic analysis is performed by economists, the procedures and tools employed and even the results produced should be rational enough for the decision-making team or different stakeholders involved in decision-making to understand (Cowdin, 2008).

Furthermore, in its decision-making process and pursuit to evaluate costs and benefits, economic analysis begins by ranking projects according to their economic viability to help allocate resources appropriately and efficiently (Edomah, 2018). According to Edomah (2018), economic analysis includes asking the following questions:

- Should the private or public sector execute the project?
- What will be the economic (fiscal) effect of the project?
- How will equity and efficiency of cost reclamation be ensured?
- What will be the environmental effect of the project?

Economic analysis involves three key components: i) identifying and estimating costs related to the project; ii) identifying and estimating benefits to be gained from an investment project; and iii) balancing outflows and inflows to establish the pertinence of the investment project (Wallstreetmojo Team, n.d; Economic Analysis: Summary of Three Methods, 2015).

Economic analysis is a vital activity in the wastewater management sector, particularly in the decision-making of system(s) efficiency, improvements and available alternatives. Various studies (Hernández-Sancho et al.,2015; Fitriani et al., 2019; López-Morales & Rodríguez-Tapia, 2019) have adopted economic analysis in the effluent management industry to aid decision-making and determining costs of implementing new or improved systems and costs of doing nothing. Given that economic analysis includes the environmental and societal costs and benefits, it provides data and evidence for governmental decision-making to enhance effluent management (Hernández-Sancho et al., 2015). Appropriate generation, removal of pollutants and harmless use or discarding

of pollutants can result in exceptional environmental and health benefits. These benefits may not be captured because they do not have market values (Hernández-Sancho et al., 2015).

However, there are different ways to determine costs and benefits without market values (intangible costs and benefits). These intangible economic inflows and outflows can be estimated with shadow prices (Molinos-Senante, 2015). Shadow price shows the impact of environmental policies on companies and, as such, can be utilised to inspect the effectiveness of environmental policies (Zhang et al., 2022). Further discussions on shadow prices will be in the cost-benefit analysis section below.

Furthermore, the economic analysis comprises several steps that guide the process for an appropriate execution. For instance, according to the Asian Development Bank (ADB, 2019), the following guidelines should be followed when conducting economic analysis of projects.

**Procedures for Project Economic Analysis according to the Asian Development Bank (ADB)**

**Coverage of the Economic Analysis**

A thoroughly performed economic analysis must indicate the following:

i. A project is compatible with the borrowing or financing party's development context..

ii. The proposed project constitutes the minimal costs and most efficient alternative amongst all the possible options for realising the anticipated project gains. At the valuation of the benefits, it will produce a positive net present value (ENPV) using the lowest recommended economic internal rate of return (EIRR).

**Recognition of Project Expenditures and Gains**

**With and Without Project Scenarios, Fixed Prices, and Project Life**

There are four comprehensive steps in project economic analysis:

i. Ascertain gross benefits and costs of the project;

ii. Calculate and determine the price of the benefits and costs, firstly in market or financial prices;

iii. Modify the costs and benefits to reveal their economic values and

iv. Balance economic expenses and economic gains for the net economic value.

**Economic Assessment of Expenses and Gains**

Economic appraisal of project expenditures and gains includes transforming their monetary values into economic values, known as *shadow pricing*. This transformation necessitates valuing the economic values of the project inputs and yields. Economic values represent prices of goods, services and related project impact on the state economy. The foundation for estimating economic values varies amid goods and services, project intakes and yields, and progressive and non-progressive intakes and yields traded and nontraded in the global market.

**Valuation of Gains in Different Sectors**

Except specified differently, benefit valuation is the aggregate gains of a project instead of its net gains, which is the gap between the total gains and expenses. Although the broad principle of benefit valuation, differentiating between non-progressive gains estimated at market prices, applies to all sectors, thorough application varies.

**Investment Judgements and Benchmarks**

Discounting and Indicators of Economic Feasibility

After identifying and assessing the benefits and cost flows of the project accumulated in different time periods of the venture's lifecycle, which is usually between 20 and 30 years, the coming cash flows should be altered to their current price (base year price) by discounting at a specific economic discount rate. The practice of discounting permits the estimation of total measures of a venture's economic viability for investment decisions-making. The frequently applied instruments to establish economic feasibility are economic net present value (ENPV) and economic internal rate of return (EIRR). Additional measures that are widely used include benefit-cost ratio (BCR) and cost-effectiveness ratio (CER).

**Sensitivity and Risk Analysis**

Economic analysis of a project employs the probable prices of economic gains and losses. Nonetheless, sources of gains and losses are subjected to several factors which may diverge from the forecast. Sensitivity analysis is intended to estimate the influence of unfavourable variations in the main variables upon the ENPV and EIRR of the project and the effects of these deviations

on the project investment decision. In contrast, risk analysis includes the possibility that the main variables will deviate from their projected prices and the associated project risk that occurs when these critical factors diverge concurrently. The methods described above valuable and applicable in measuring the effects of risk on investment decisions and ought to be utilised to inform the problem-solving plan.

**Project sustainability**

Economic feasibility is determined by the long-term viability of project results. Therefore, the economic analysis of a project ought to guarantee that a sufficient analysis of the financial and organizational sustainability of the funding party and the project's environmental sustainability has been conducted.

### 4.4.2 Cost-benefit analysis (CBA)

**Welfare economics as the foundation of CBA**

The theoretical fundamentals for CBA are given by welfare economics (Boadway & Bruce, 1984). According to Koopmans and Mouter (2020), welfare economics studies the public interest of alternative economic conditions: a case including a state project and one excluding a project. Put differently, welfare economics is founded on of Paretian efficiency (optimality) theory. Pareto optimality is a situation whereby resources in a set system are utilised to their best effective use, resulting in a condition in which one dimension cannot get better without making another worse (Suffian, 2016). At this point, no allocation of resources can improve someone's situation without concurrently making someone else's situation worse. According to the traditional welfare economic theory, which is predicated on atomistic and open-market circumstances, proceeds on investments assess the improvement in well-being from those project ventures (Conningarth Economists, 2007). On the other hand, welfare can be measured by the use of marginal willingness to pay (MWP), which is believed to gauge the welfare brought about by consumption based on the idea that, at the individual level, the larger the expected welfare from consumption, the better (Carbonnier, 2023). Based on these premises, and given that the results of perfectly competitive marketplaces are Pareto optimal —in its pursuit to achieve efficiency, CBA operates like a perfectly competitive market (Carbonnier, 2023).

The efficiency theory is widely applied in public economics when analysing government decisions (e.g., taxes, government spending, regulations and the like) on the country's economy. Classic examples in welfare economics include (but are not limited to) healthcare, education and social security benefits. In welfare economics, gains are described as improvements in social security of humanity (utility), and losses are described as deterioration in the wellbeing of humanity (Pearce et al., 2006). To be considered cost-benefit, a project or program must have social advantages that outweigh its social costs. Two fundamental guidelines of aggregation exist. First, aggregating gains must be aggregated across various socioeconomic groups (countries) requires adding willingness to spend for gains or willingness to accept reimbursement for costs (WTP, WTA, respectively), independent of the winners' or losers' situations (Pearce et al., 2006). According to a second aggregation rule, benefits and expenditures incurred by low-income or disadvantaged groups must be given more weight. The concepts of WTP and WTA are closely related to those of compensating and equivalent variations and are firmly rooted in welfare economics theory (Pearce et al., 2006).

Typically, the wellbeing of society is viewed as a logical extension of the utility (or welfare) of individual people (Beckerman, 2011). As a result, the ordering of economic circumstances is determined by adding together various utility functions. Given the difficulty to directly determine utility for individuals, economists posit that it could be deduced from their decision-making behaviour when presented with different options (Beckerman, 2011). According to Fuguitt and Wilcox (1999), welfare economics assumes that decisions people make within their financial constraints can be used to determine the value of both consumption products and the consequences of government programs. Individuals' willingness to pay with their taxable earnings in (fictitious) markets can be used to quantify the utility they obtain from consumer items and the effects of governmental initiatives. The willingness to pay can be calculated using survey data or market behaviour.

Additionally, there were several critiques of CBA based on its weaknesses in the Pareto principle, including: i) how well-founded theoretically CBA is, as evidenced by the Kaldor-Hicks reimbursement assessment in welfare economics; ii) considering that the fundamental "social welfare function" in CBA is among the disproportionately sizable amount of functions where agreement is unlikely; iii) the degree to which it is ethically justified to base social decision-making

principles primarily on individual preferences. (Carbonnier, 2023). Studies on the welfare economics have perpetually challenged the tenets and presumptions fundamental to CBA, despite the required theoretical groundwork provided for an effective benefit-cost rule.

The presentation of CBA as a tool that looks for "Pareto improvements"—adjustments that will increase the utility of an individual while not diminishing the utility of the next individual—is one approach in which the welfare economics can avoid the contentious assumptions outlined above (Ingle, 2014). These adjustments will improve social wellbeing, although it may be challenging for government regulations to meet this requirement in the real world. However, some of the CBA shortcomings were tackled by the Kaldor-Hicks compensation concept. The Kaldor-Hicks principle, that regulates the Pareto conditions by allowing the probability of reimbursement (Hicks, 1939; Kaldor, 1939), is a more valuable idea. According to the Kaldor-Hicks principle, a regulation (or amendments) has a potential to increase welfare provided that the beneficiaries make up for the ones who lose out, leading to a Pareto improvement after compensation. The Kaldor-Hicks principle is the foundation for most conventional CBAs (Koopmans & Mouter, 2020).

The Kaldor-Hicks concept, however, calls for the possibility of compensation, not its actual occurrence (Pearce, 1998). The principle has also been criticised for overlooking equality because it does not capture who loses and who gains (Conningarth Economists, 2007). Issues with this principle were on the hypothetical basis and its theoretical validity. In addition to that, the issue of redistribution of income. There is a redistribution of income when losers are not rewarded, indicating that distributional effects also required to be taken into account in the CBA's objective function (Dasgupta & Pearce, 1972).

If there were still any restrictions on optimality, it would likely reduce welfare (and possibly increase it). Last, many academics thought welfare economics was intellectually doomed after de Villiers Graaf (1957) attacked its several components (Pearce, 1983).

However, using a Bergson social welfare function (Bergson, 1938) was one strategy that more overtly included equity. The varied weighting of the net benefits of various groups is a feature of this kind of utility function (Schofield, 1987). In light of the non-uniqueness of Pareto optima, it is essential to identify the best optimum among the potential optima by using a social welfare function. The optimal optimum would be determined by the joining point of all potential Pareto optima and the social welfare function's shape (Winch, 1971). If a Bergson social welfare function

is applied, values for the different weights must be determined. A democratic procedure would be one way to do this.

Nevertheless, Arrow's Impossibility Theorem demonstrated that under a specific set of "reasonableness" requirements, no social utility function could exist. As a result, individual preferences could not be combined without injecting some ethical judgment (Dasgupta & Pearce, 1972). Therefore, it appeared that additional methods—possibly bureaucrats or the analysts themselves—would have to be used to allocate weights. These two factors each have the potential to make these weights subjective (Schofield, 1987).

On the other hand, market outcomes are not constantly Pareto optimal and are unproductive when sufficient circumstances for Pareto optimality are not in effect. As such, market failure is believed to exist in these circumstances. To draw near to a Pareto ideal result, welfare economists then try to assess and suggest "corrective" measures for discovered market distortions (Boadway & Bruce, 1984). However, Lipsey and Lancaster (1956–1957) demonstrated that in non-optimal circumstances, the steady rectification of market distortions (including those in CBA) would not imply an improvement in social welfare (may actually diminish it) given some additional limitations to optimality persisted.

Lastly, many academics thought welfare economics was rationally disaster-prone after de Villiers Graaf (1957) attacked its several components (Pearce, 1983). Given these critiques on welfare economics and the fact that CBA is primarily the effective formula of welfare economics (Barbier et al., 1990), it is puzzling that it survived and grew stronger during the time of the critiques. According to Pearce and Nash (1981), this was likely because of the need for an applied economics-based evaluation of the escalating government spending in that period. Pure financial evaluation, which had a limited scope was therefore only partially useful to the appraisal of civic projects, was the alternative to CBA during this time.

**Determining social costs and benefits: Shadow pricing**

Generally, the Cost Benefit Analysis (CBA) is intended to enhance microeconomic allocative efficiency by altering market failures. The centre of interest is on recognising projects that do not only have a private impact (profits or losses) but also carry a possibility of social impacts (profits or losses) and, therefore, a public cost or benefit (Robalino & Walker, 2017). Private and social profitability may differ due to the response of private agents to market prices, which can be biased due to various market failures (Robalino & Walker, 2017). For instance, the input prices may not fully reflect the cost of economic opportunity, and market proceeds may underplay or exaggerate the social cost or benefit of the project.

Given that the CBA operates like a perfectly competitive market, it fundamentally addresses the question, "Would the project under consideration be put forward in a world of perfect competition, with no externalities, public goods, or increasing returns to scale?" (Conningarth Economists, 2007). The real world is imperfect, as such projects sometimes proceed differently than planned. Project costs and benefits may need to be altered to account for the fact that, in reality, the world is not without flaws (Bhattacharyya et al., 2019), as such shadow pricing (efficient value) is used when there are market flaws. These imperfections consist of externalities, imperfect competition, taxes, trade controls, and the like.

In decision-making processes where commodities or resources lack explicit market prices, shadow pricing is essential (Thomas & Chindarkar, 2019). Shadow pricing offers a valuable tool to enable thorough and comprehensive decision-making, whether evaluating policy alternatives, quantifying intangible aspects, or measuring the environmental impact of a project (Karan, 2023). Therefore, a shadow cost is an economic notion that considers allocating a fictitious monetary value to a good or service that does not have a clear market price. It influences economic decision-making by estimating the economic value of commodities or services not exchanged on a typical market (Karan, 2023). When public goods, externalities, or environmental resources do not have explicit market prices, shadow pricing is utilised to measure the expenses and gains. Economists seek to account for the actual value of such resources in economic assessments by putting a shadow price on them (Karan, 2023).

In addition, shadow values demonstrate a marginal impact on social wellbeing (Yamaguchi & Managi, 2019) and thus determine the net social benefit. From various potential resource allocations, net social benefit selects the most effective one. In essence, the option with the highest net social benefit among those considered in a CBA represents the most equitable choice (presuming that the projects are mutually exclusive) (University of Queensland, n.d). Economists also frequently allocate a "shadow price" to calculate the cost of negative externalities, such as pollution produced by a corporation (Hayes, 2021).

When conducting a cost-benefit analysis, a firm must frequently take into account the expenses or gains of non-physical assets that are challenging to put a price on, but that nevertheless need to be monetarily valued in order to conduct the study (Bhasin, 2023). The practice of shadow price aids a business in comprehending the actual value of a project better. Shadow pricing is a vital element of CBA and instrumental in supporting managerial decision-making about various aspects of the strategy of the project and its scope. (Karan, 2023). Shadow pricing a critical and unbiased evaluation tool that promotes ethical behaviour (Hayes, 2021).

Nonetheless, shadow pricing involves some weaknesses, the main being its level of subjectivity and lack of evidence resulting from the ethereal pricing method (Bhasin, 2023). Secondly, the numerous assumption made by an analyst creates room for bias. Hence, there are high probabilities that the estimated shadow prices are erroneous (Karan, 2023). If the procedure followed to estimate the shadow price is faulty, the organisation may choose to take steps that are inefficient and can tarnish its reputation (Hayes, 2021).

Despite its limitations, shadow pricing is still one approach that is extensively used in private and public sector organisations for project appraisal purposes to determine the price of cost or benefits without market value. According to Cairncross (1976), organisations such as the World Bank have calculated shadow prices for over 25 years and the British Treasury for over a decade. If market imperfections, more common in developing nations, are not considered in CBAs, this could produce false outcomes (Omura, 2004). Due to market distortions, a project may appear viable to a businessperson, but from a public standpoint, it may not pass the cost-benefit assessment.

**When to use a cost-benefit analysis**

When considering to go for particular step or not, for instance, introducing a fresh product range, revamping a current one, opening a new place, or hiring more personnel, a cost-benefit analysis is utilised (Juma, 2023). When the activity contains tangible monetary expenses instead of just estimates, this technique is most beneficial.

Cost-benefit analysis might also be applied when creating a fresh business method or plan, making a decision on whether to accept a novel project, estimating the potential effect of a new company policy, deciding how to allocate resources or what to buy for a project and examining structural alterations to the organisation (Juma, 2023). However, people can conduct a cost-benefit analysis outside business, such as determining whether to relocate and accept a new job. In this case, they can weigh the potential increase in income from the new employment against the cost of living in the new place to determine whether accepting the post is the right move.

Furthermore, according to the United States Department of Transport (2020), the purpose of calculating and determining cost-benefit analysis advantages and disadvantages of an investment is twofold:

1. To examine whether the project is feasible and a wise investment.

2. To compare the feasibility of one project investment to those of other initiatives.

It enables project evaluation by decision-makers to be uniform and comparable.

Both businesses and governments frequently take CBA into account when making investment decisions. Businesses typically focus primarily on their expenses and advantages. In contrast, government choices may take a broad (or all) range of individuals and businesses in their jurisdiction into account (The University of Queensland, 2022). The cost-benefit analysis for governmental choices is frequently referred to as social cost-benefit analysis due to its extensive reach.

**Practical application of CBA**

Cost-benefit Analysis (CBA) is a valuable device for decision-making to estimate cost-benefit expenditure projects in different fields (Agriculture, Health, Finance and others) (Bumbescu & Voiculescu, 2014). In economic analysis studies, the CBA is an extensively used tool as it is

considered sensible and a methodical instrument that supports decision-making (Djukic et al., 2016). The goal of cost-benefit analysis is to offer a standardised process for assessing choices in terms of their outcomes (Drèze & Stern, 1987). Put differently, CBA seeks to recognise and measure the effects of a venture or activity in to help decide on the proper costs and benefits (Omura, 2004). All effects must be compared to the goals and evaluated regarding their financial, economic, social and environmental effects.

A planned course of action's total benefits and costs are calculated systematically and compared to other possible courses of action (alternatives) (Omura, 2004). Costs and benefits are evaluated through a method known as the "incremental approach", which compares "with project" and "without project" scenarios (Bumbescu & Voiculescu, 2014). The decision to pursue such a course of action is determined by the final net value, which may be positive or negative. By highlighting the benefits and downsides of the project and other potential alternatives, given the budgetary constraints, the adoption of such effectiveness standards is central to civic decision-making regarding government investments facilities, growth projects and ecological policies. (Omura, 2004). Thus, the CBA is a device for making judgements that evaluate the usefulness of investments.

In addition, considering that benefits and costs accumulate over time, decisions have to be made at present, and benefits and costs of this kind need to be discounted to the present (Omura, 2004). CBA calculations require that losses and gains are discounted to the benchmark year. For instance, this principle is on the premise that the R100's benefit in the present is not of the same worth with the with a R100 years to come.

CBA, as an economic valuation method**,** studies the economic gains and losses of a given program by balancing the discounted flows of losses and gains within a given timeframe (Dixon, 2012). Data to be analysed must include timeframe (project lifetime), values of project costs and benefits (given in currency value) for all the years considered in the analysis, interest and the discount rate (Dixon, 2012).

Discounting is fundamental to economics because it makes it possible to compare impacts at different points by turning each future dollar into an equivalent amount of present dollars (Gollier & Weitzman, 2010). This tool is intended to forecast how the values of losses and gains would adjust over time, for instance, measuring how these values will be impacted by inflation (MacNeil,

2022). Put differently, discount rates are interest rates applied to future expenses and gains to convert them to their present value. Proper estimation of the current value of the costs and benefits can then be accurately determined (MacNeil, 2022).

Also, it must be noted that there is an opportunity cost involved in selecting a project over given alternatives. The opportunity cost of the selected project could be determined by looking at its financial cost, which displays the market value of the resources it displaces (Dasgupta & Pearce, 1972).

Furthermore, an effective CBA needs the analyst to follow a logical flow of operations. What project or policy is being examined is the first pertinent question to ask. What are the alternatives? The current price of gains must be greater than the current price of losses for the primary assessment of the program policy's contribution to the social welfare to be deemed suitable (Pearce et al., 2006). A second primary step in CBA is determining "standing," or whose expenses and benefits are to be counted, as well as the time frame. People have inclinations for when they want to get gains or pay expenses. Therefore, the discounting process also needs to take these "time preferences" into consideration. Similar to how preferences for or against an influence can evolve, this "relative price" effect must also be considered. Inconveniences must also be accounted for through risk and uncertainty because losses and gains are seldom known with absolute certainty. The distributional incidence of costs and benefits must also be determined. In addition, below is a detailed discussion of the steps in preparing a CBA.

**CBA as a conceptual framework**

Most literature on CBA describes the procedures to prepare a CBA, which entails following a standard flowchart. Although these steps vary in different studies, there is enough similarity to imply a broad strategy. The overall method is then discussed, followed by typical approaches to external effects, discounting, and choice criteria (Sassone & Schaffer, 1978). At this stage, the prospective project should be described, followed by specifications of project alternatives. The steps to conducting CBA are as follows:

**1. Define the decision problem to be addressed**

The decision-maker should be consulted early on in the CBA process to go over the objective, parameters, and coverage of the project. The analyst must make critical decisions on the purpose

and the primary components of the economic evaluation in the first step of CBA (Guerriero, 2020). The most crucial decision is to identify the question(s) being answered, mainly: (1) stating the problem and (2) the policy (project) alternatives evaluated in the analysis, including non-action (Guerriero, 2020).

**2. Determine and estimate incremental costs and benefits of the alternatives**

The second phase in doing a CBA as part of a program evaluation is to list and classify as many of the program's known costs and benefits as possible (Riegg & Edwin, 2015). While it is impossible to know all costs and benefits with certainty, the analyst should try to pinpoint those that will have the most effects on the policy (project). Not all of these consequences will call for a monetary assessment (Riegg & Edwin, 2015). However, it is advisable to appraise potential gains and losses broadly in the early phases of investigation.

**3. Match the costs and benefit sources of the alternatives**

Gains and losses are compared after totalling them to determine which value is higher on all the alternatives. If the cost value of the proposed project is higher than its benefits, then it may be better not to implement the new project (Juma, 2023).

The expenses and gains that are sustained during the timeframe of the project must first be discounted before they can be compared directly. The project's economic value is then compared with its alternatives using decision rules (Conningarth Economists, 2007).

**4. Perform a sensitivity analysis**

The reliability of the CBA outputs concerning the assumptions that underlie them (specifically, the discount rate and the income distributional weights) must be verified (DEAT, 2004). Doing so promotes accountability by making the final decision-maker's priorities apparent.

**5. Present the results and make recommendations**

Finally, the CBA's findings are synthesised by the analyst and presented to the decision-makers. This process incorporates a succinct summary of costs, benefits, and net effect. It links the findings to the main objective, indicating how it ultimately corroborates the initial purpose of the analysis

(Hayes, 2023). Findings are presented as a report consisting of recommendations founded on net-present values (NPVs) of the policy alternatives and the sensitivity analysis (Boardman et al., 2001).

**Decision rules**

A variety of decision rules may be applied to compare costs and benefits. The net present value or "net benefits" measure is the appropriate one to use when reducing both benefits and expenses to a single number (Pearce et al., 2006). Any venture with a positive NPV should be adopted, and projects alternatives should be ranked according to their NPVs. However, the conditions become more complicated when there are financial limitations. A benefit-cost ratio (B/C) ranking process can be used to address single-period restrictions, such as capital shortages. There is a broad consensus that independent projects ought not to be ranked or chosen using the internal rate of return (IRR) (Pearce et al., 2006).

The question is whether the IRR adds valuable extra information when a venture is the only program proposed for changing the current situation. The opinions on this matter vary. Some contend that calculating statistics that are deceptive or subordinate to the NPV has no significance (Pearce et al., 2006). Other scholars believe that the IRR can provide a clear indication of the extent sensitivity of the net benefits of a project to the discount rate. However, regardless of the viewpoint, the fundamental conclusion of the NPV rule's general supremacy remains the same (OECD, 2006).

Cost-benefit analysis (CBA) consists of several systematic instruments to evaluate the financial and economic feasibility of a recommended project. The systematic instruments that can be applied consists the benefit-cost Ratio, Net Present Value, Internal Rate of Return, Least Cost Planning, Payback Period, and Sensitivity Analysis (OECD, 2006). Further discussion of the decision tools is below.

**a) Net Present Value (NPV)**

Net present value (NPV) is also known as the present-day amount of the cash flows at the necessary rate of return of a venture matched to the principal investment. In reality, it calculates a return on investment (ROI) for a venture or spending. A decision on a project's worthiness can be made by considering all the money expected through the project life and converting those returns into

today's dollars (Gallo, 2015). This method also suggests that it evaluates whether a net impact on social welfare transpires through present value calculation. Tang and Tang (2003) indicated that IRR provides the private investor's viewpoint while NPV presents the society's perspective.

While these two methods (NPV and IRR) are extensively used they have their acknowledged limitations: IRR's weaknesses include manifold rates, the postulation that revenues are reinvested at the IRR, and the scale influence (de Souza Rangel, de Souza Santos & Savoia, 2016). On the other hand, the NPV approach does not show the cost of investment attached to the program, which is problematic when comparing projects with differing principal investments (Lewis, 1998). To overcome the shortcomings of the two methods above, a third method -Benefit-cost Ratio (BCR) was introduced.

**b) Benefit-cost Ratio (CBR) /Profitability Index (PI)**

The benefit-cost Ratio (BCR) is the profitability indicator (PI) that is instrumental in calculating the amount of benefits or losses and the project viability (Rukmana & Muslim, 2017). The net benefits and costs over a given period are calculated with a baseline occasion. BCR can be measured in two ways: i) by the present value (PV) of future benefits over the PV of costs (with investment and yearly operating costs, or ii) by taking the PV of future net benefits over the once-off investment costs (Dixon, 2012). The BCR method is closely associated with the NPV rule, making it more significant. These methods go hand-in-hand; for instance, if the BCR is less than one, the NPV is negative, and the opposite is true (Rangel et al., 2016). The former is regularly used rather than the latter as it is more straightforward to understand. While these two methods typically result to the same acceptance or rejection judgment of a project, the BCR further indicates the possible amount a project may generate or lose (Ermenyi, 2015). However, BCR likewise has limitations. BCR limitations include that its estimation necessitates the discount rate, and the estimation is futile for mutually exclusive projects in that it might lead to incorrect decision instruction (DEAT, 2004).

**c) Internal Rate of Return (IRR)**

An ideal rate of return is a level upon which the investment cost is equivalent to the present-day price of future cash flows. A project that is capable of accomplishing this is effective and

beneficial. Put differently, at this rate, the cash outflows and their present value are equal, making the project attractive (Investopedia, 2021). The IRR is called the 'hurdle rate' since it generally offers the lowest satisfactory returns. This measure is alternatively called the Economic Internal Rate of Return (EIRR) in cases where the study is performed with "economic" prices that eliminate any policy biases (such as government regulations in the markets for inputs or outputs (Dixon, 2012). IRR is mainly instrumental as it provides an instinctual logic to decision and policy makers and contains the total cash flow linked to a project (DEAT, 2004). This method captures the time value of money.

**d) Modified Internal Rate of Return (IRR)**

The modified internal rate of return (MIRR) is a financial tool of helpful measurement to evaluate the lucrativeness of a business venture and rate alternative investments that are equivalent to it (Cheusheva, 2023). MIRR is designed to overcome the limitations of the IRR. While the IRR merely ensures the reinvestment of the positive cash flows at a particular rate of return (RoR) of a project, MIRR permits the specification of a differing reinvestment rate for imminent cash flows (FreshBooks, 2023). It is an advanced method for project appraisal. It is more flexible as it enables modification of the projected rate of return (RoR) in different phases of a long-term project. MIRR precisely reveals the profitability and success of an investment project as it reflects the finance and reinvestment rate to discount negative cash flows (Cheusheva, 2023). MIRR is a more realistic measure than IRR as it is helpful to elude any capital budgeting inaccuracies that can result from IRR.

However, this technique has some intrinsic shortcomings; the main issue is that some finance professionals believe that the rate of return generated from MIRR lacks consistency because proceeds from a project are not reinvested in full all the time (Cheusheva, 2023).

**e) Payback Period (PP)**

The payback period is another helpful tool for project appraisal that evaluates the project viability through the lens of the time factor. The payback period is the time that can be viewed as an estimated period of the investment project payback (Gorshkov *et* al., 2018). For instance, a future date whereby aggregate economic impact is realised as an outcome of the SSF effluent treatment

system is equivalent to the value of the initial investment. A payback period of an investment that is less than the projected service term of the executed practical solution can be viewed as economically reasonable (Gorshkov *et* al., 2018).

**f) Discounted payback period (DPP)**

DPP is the time duration where the aggregate net present value of a project's cash flows takes the value zero. If DPP is shorter than the economic life of the project, it is accepted. DPP embraces all the valuable qualities of the conventional PP and has a remarkable correlation with the NPV, IRR and PI principles (Bhandari, 2009). DPP solves two main shortcomings of the PP principle by accounting for the time value of money and through the unbiased decision-making principle. As such, this technique guarantees the liquidity and profitability of venture capital, which makes it superior to the NPV and PP (Bhandari, 2009). DPP can often be the highly preferred measure over other investment appraisal methods such as NPV, IRR, MIRR and PI.

Other benefits of the DPP method include its simplicity and straightforwardness, which makes it easy to estimate and comprehend. Also, DPP is applauded for its ability to accurately calculate the recovery of the initial investment, which makes it more significant to account for uncertainty in the project than the PP technique.

However, the main limitation of the DPP is that by design, it is constantly longer (higher) than the PP, the method in its criterion can decline and investment in which the PP has approved as liquid.

### 4.4.3 Cost-effectiveness analysis (CEA)

Cost-effectiveness analysis (CEA) is regarded as a distinct type of cost–benefit analysis. This evaluation method is centred on a principle of non-monetisation effect whereby the gains and expenses of different program alternatives are equated in non-monetary units to evaluate the effect and achieve a specific objective (Romijn & Renes, 2013). For instance, in scenarios where the welfare cannot be precisely estimated, CEA makes a cost comparison of differing methods of accomplishing the set goal to detect the least cost alternative (Vaughan & Ardila, 1993). Put differently, cost-effectiveness analysis requires that natural units of measurement must be used to

measure program effectiveness and estimate the desired program implications expressed in the same dimension (Robinson, 1993a). For instance, units that are used in health interventions include per life saved, per case detected, per life year gained, etcetera (Robinson, 1993a; Tolpin, 1988)

According to Romijn and Renes (2013), the research methods of CEA are the same as that of CBA, and these two techniques are similar in structure. However, CEA is mostly appropriate where feasibility in estimating benefits is not guaranteed (Maliva, 2014). The CEA method also differs from the CBA in that it does not consider a low-budget (costs) project policy as the most effective policy alternative and the opposite is true (Quain, 2018). CEA is conducted on a predetermined goal or outcome (exogenous), which means that CEA is best applied to compare alternative programs that are intended to accomplish a common goal (Tolpin, 1988). Therefore, this method of economic analysis does not permit a comparison of program interventions with diverse goals, which is one limitation of the CEA method. Another limitation of the CEA method is that primary data collection for CEA is generally expensive and time-consuming. As such, CEAs are conducted mainly on data that is readily available (Robinson, 1993a).

### 4.4.4 Cost-utility analysis (CUA)

A cost-utility analysis (CUA) is an economic evaluation that compares the expenses and outcomes of different interventions (Office for Health Improvement and Disparities, 2020). CUA involves comparing the incremental expenses of the intervention to the incremental health improvement (Rai & Goyal, 2018). A cost-utility analysis (CUA) is a particular case of CEA whereby welfare is demonstrated as a utility measure, which is a measure based on individual preferences (Kepler, 2012). This measure can be applied to estimate the quality-adjusted life years (QALYs) (Robinson, 1993b). Put differently, CUA assesses health outcomes based on quantity (life years) and quality of life (Office for Health Improvement and Disparities, 2020). From the viewpoint of payers and policymakers, the importance of particular kinds of interventions should be compared with others across similar disciplines. CUA's reliance on preference-based utility measures supplies information that makes this comparison possible across different medical specialities (Kepler, 2012). Policymakers and payers will likely utilise this form of economic analysis as a guideline for making coverage decisions. CUA is the best economic evaluation method used in making decisions about health resource allocation (Robinson, 1993b).

However, two main factors spark controversy in using CUA as a decision-making instrument. The main point of contention is whether the financial discount rates should be equivalent to health discount rates, as well as whether the time discounting and time preferences are best suitable (Nuijten & Dubois. 2011). Most researchers believe that gains and expenses should be discounted equally (Gold et al., 1996). Conversely, specialists recognise that the justification for using identical discount rates for expenditures and health effects needs to be sufficiently defined in the published recommendations (Claxton et al., 2006). Some scholars have proposed that the cost of health increases with time, and hence, the health impacts' discount rate ought to be lower than the discount rate on expenses (Brouwer et al., 2005).

Another methodological point of contention is the utility idea. In cost-effectiveness analysis, health outcomes are frequently stated regarding life years gained (Nuijten & Dubois. 2011). Although QALYs represent a significant advancement in cost-effectiveness analysis, their application is complex. The application of QALYs does not mean that justice and equity in health care are automatically considered (Nuijten & Dubois. 2011). Also, there are significant measurement issues in determining QALYs. There are several strategies for assigning a price to a specific health state, such as the classic gamble and the time trade-off, but there is almost no agreement on which technique is best (Nuijten & Dubois. 2011). The issue is that these methodologies produce vastly disparate findings, resulting in disparate cost-effectiveness outcomes, as Joree et al. (2010) demonstrated.



## 4.5 Empirical Studies on Economic Analysis of Wastewater Treatment Plants

In a world full of uncertainties, it is of utmost importance to assess any new project's feasibility. Investors are generally attracted to invest in projects where returns are guaranteed or at least anticipated. Evaluating the economic viability of the SSF plant at Winery X is, therefore, a necessary condition that will determine whether the project is economically and financially feasible. A broad scope of economic evaluation of the relevant expenses and gains resulting from wastewater treatment is required to safeguard longstanding economic, environmental, and social sustainability (Arborea et al., 2017).

Empirical studies deliver substantial evidence on the economic feasibility of effluent treatment plants in the real world. Different economic methods based on real-world case studies have been applied. One can accurately measure the economic impact through analysis of real-world case studies. Incidences of economic analysis of WWTP are discussed below.

Ordinarily, wastewater treatment techniques include fusing physical, chemical and biological procedures and measures to eradicate inexplicable particles and soluble pollutants from effluents (Crini & Lichtfouse, 2019). Several techniques categorised in conventional methods, recognised recovery processes and emerging removal methods can be used. Among others, these methods include coagulation/flocculation, membrane separation and Nano-filtration in the abovementioned categories (Crini &. Lichtfouse, 2019). The WWTP in the said categories contains many disadvantages, which present a severe constraint on the growth and sustainability of the wineries, calling for more studies of novel technologies.

Although the central focus of this study is evaluating the economic feasibility of the wastewater plants, the environmental and social impact of the wastewater plants cannot be ignored. As such, a study by Fitriani et al. (2019) analysed the economic feasibility of wastewater plants, focusing on feasible rate determination. The study used two scenarios: the ability to pay and the willingness of users (the public) to pay. Sensitivity analysis of net present value (NPV) was also conducted in different circumstances. The feasibility analysis was based on the benefits and costs sustained over 20 years. Based on the ability to pay, the NPV and BCR were economically viable; however, when the decision was made based on the willingness to pay, the results suggested that it would be economically infeasible to construct the suggested WWTP.

That said, wastewater treatment practice results in social and environmental (external) benefits that need to be calculated and captured to measure the economic viability of a suggested project (Molinos-Senante et al., 2010). A study based in Serbia, calculated indicators for the economic performance of a building project necessitating tertiary wastewater treatment through a cost-benefit analysis methodology. The philosophy of full cost recovery and "the polluter pays" was considered. In this study, financial sustainability was evaluated by calculating cost-reflective

tariffs. A favourable outcome was indicated whereby the economic NPV was positive, and EIRR was higher than the social discount rate (Djukic et al., 2016).

Full cost recovery indicated a noteworthy rise in the tariff that is worth considering for decision-makers to account for both economic feasibility and social affordability. However, a project might also produce some adverse outputs, economically termed negative externalities. As such, calculating shadow prices has been a helpful valuation method for externalities that create significant environmental influences (Molinos-Senante et al., 2010).

Another study conducted in Portugal applied a different instrument for the economic analysis of effluent treatment. This study sought to capture the economic likelihood of employing biomethane plants in WWTP. The discount cash flow method was applied to evaluate the economic feasibility of producing biomethane in a WWTP in Évora (Portugal). The findings revealed that, at that point, it would be unbeneficial to produce biomethane in the WWTP (Baena-Moreno et al., 2021). The results further revealed that a possible additional income would be generated through selling the carbon dioxide separated from biogas, which would be an excellent option to consider. However, selling carbon dioxide is not necessarily a way of achieving profitability on the biomethane plants.

From a different perspective, Arborea et al. (2017) studied the advancements in the economic assessment of effluent reuse. The CBA of wastewater project plants was the method of enquiry. The approach studied two different settings of using treated water for irrigation purposes. The results revealed that enhanced effluent treatment would improve the regional accessibility to irrigation water. The study also revealed that unlike treatment costs, which largely depend on the quality of incoming effluents and plant size, benefits are generally steady (Arborea et al., 2017).

Furthermore, there are many studies on wastewater treatment costs. Comparability of outcomes is, however, limited because it represents a variety of methodological techniques and types of expenses addressed. At the same time, some scholars (Edokpayi et al., 2017 and Sheridan et al., 2005) include quality aspects (for instance, the toxins removed or the nature of the influent and effluent). In contrast, other studies simply research the quantity (Latessa et al., 2023 and Masi et al., 2015) of treated wastewater. Additionally, some projects approach operation and maintenance

costs by solely estimating expenditure on energy, while others calculate all treatment costs involved (Flores et al, 2020 and Kyzas et al., 2016). Finding common indicators that enable scale comparisons is crucial (Murray et al., 2011). The following is a description of some research that calculates the costs of wastewater treatment using an engineering method.

In order to shed light on the connection between wastewater treatment expenses and the quantity of effluent treated, Rodrguez-Garcia et al. (2011) employed an engineering method. Centered on a trial of 24 treatment facilities in Spain, the researchers evaluated the effective expenses of primary, secondary, and tertiary treatment for six types of WWTPs. They grouped WWTPs on the criteria for the effluent's quality based on the kind of discharge landing place or the intended use of recovered water.

The findings indicate that the expense and global warming potential of acquiring the best quality effluent (sterilized and with less nutrient pollution potential) are inversely correlated. On the other hand, limited removal of organic debris resulted in a more economical strategy to reduce eutrophication (Rodrguez-Garcia et al., 2011). In conclusion, a wastewater treatment system must meet its final intended goals with regards to environmental, social, and economic needs in order to be deemed sustainable. Therefore, it is crucial to combine social factors with the already established methodology to achieve a whole set of sustainability indicators for each wastewater management intervention.

**The case study of Winery X: Wastewater Treatment Challenges confronted by the Winery**

Winery X Vineyards is among the most extensive wine cellars in South Africa, located on the land along the edge of the Olifants River. The vineyards draw their water supply from the Clanwilliam Dam through a waterway system that covers over 321 km (Kriel, 2008). Their annual production ranges from 30 to 40 million litres of wine annually using a measured average of 100 thousand $m^3$ (Kriel, 2008). Previously (around 2008), Winery X wastewater would be sprinkled on 8 hectares of the Matzikama Municipality land. However, the municipality pursued a project which would permit a community syndicate of small farmers to cultivate the land and use it for commercial purposes using wastewater and some water from the Olifants River irrigation canal. While Hendrik Krohn, director of technical services of Matsikama Municipality, indicated that small wineries were spotted for the project, nothing happened due to the water quality requirements. Upon

spending R3 million on a broad water treatment and irrigation system, Winery X believed that with slight procedural modifications, water quality could be upgraded to irrigation standards.

Winery X location has a perpetual wind element, which results in high evaporation rates, and the residual water has a significantly high chemical oxygen demand (COD) (Kriel, 2008). This reveals the amount of pressure the Winery is experiencing, which requires drastic measures to be put in place. However, it is good to be cognizant that cellar wastewater vastly differs from municipal wastewater. The supply chain of wine production generates waste with highly acidic effluents, which require different types of bacteria for treatment. Subsequently, it becomes difficult for the cellar to discharge its wastewater to the municipality sewage system. Winery X treated wastewater has a COD of 2000mg/a and 7000mg/a on-peak period, which is higher than the COD stipulated by the Department of Water Affairs and Forestry (DWAF: 5000mg/a) (Kriel, 2008).

During the harvest times, the Winery X cellar is washed every evening, and the wastewater contains a bulk of grape skins. Getting rid of these products from the Winery's system eliminates the organic content of the wastewater. The water must then undergo treatment processes to remove most solids, as they are the leading cause of pump corrosion, which is environmentally unfriendly and may be hazardous to human health. However, the effluent discharge and wastewater treatment issue includes Winery X. Other small wineries experience similar challenges.

Therefore, small-footprint wineries (including Winery X), mainly in the rural areas, are struggling with large amounts of effluent that results in severe environmental and social implications. Unfortunately, apart from strict regulations imposed by the government and high environmental taxes, particularly for small-footprint wineries, the treatment costs are high. Consequently, this drew a noticeable attention in the body of research (Mulidzi et al., 2020; Howell & Myburgh, 2018; Howell et al., 2016 and Conradie et al., 2014) to study the implementation of various innovative technological methods to eliminate the impacts of wastewater from the wineries. Seeing that the traditional methods for water reuse do not necessarily solve the problem entirely, the novel technologies have been extensively considered as better alternatives. Due to the number of negative externalities that arise from the winery supply chain and unbearable costs incurred in the process, Winery X was then deemed a suitable case study to evaluate the economic viability of the novel wastewater treatment plant installed there.

Given the primary objective of wastewater treatment plants (WWTPs), which is to curtail the environmental effects of the discharged effluence into natural water systems, their performance characteristics should, therefore, safeguard the environment through minimising adverse impact (Jajac et al., 2019). Also, the WWTPs should be designed to efficiently manage the energy and water resources, and waste generation to fulfil the long-term needs for ecological sustainability (Zhou et al., 2020).

## 4.6 Conclusion

This chapter provided a succinct historical background of economic analysis and CBA, in particular, the definition of concepts, the theoretical basis of CBA and empirical research. Three primary economic analysis approaches were covered in this chapter, including CBA as the preferred economic analysis technique. Despite academic reservations about its theoretical foundation, CBA is nonetheless widely used not only by public decision-makers but by private decision-makers as well, especially for the evaluation of novel (commercial) projects. Also, the empirical studies on wastewater treatment and reuse methods indicate the prevalence of the CBA application in evaluating the economic viability of employing novel technologies to treat winery wastewater to reduce its environmental hazards and achieve compliance. This chapter further discussed the winery wastewater compliance issue at the Winery X. However, the least investigated aspect of wastewater regeneration and reuse research is its economic viability to achieve environmental compliance, particularly in the South African context (wine industry). This study contributes to the body of research by addressing the said issue. Therefore, given its versatility for decision-making, the cost-benefit method is without a doubt the best and most relevant economic analysis method used in this study. This method is conducive to determine the economic costs and benefits of the shear separation floatation technology for the Winery X.

# CHAPTER 5: RESEARCH METHODOLOGY

## 5.1 Introduction

This chapter defines research methods adopted in conducting this study. Firstly, this research forms part of a bigger research project conducted by WINETECH in partnership with ABRIMIX and the South African Institute for Advanced Materials Chemistry (SAIAMC) at University of the Western Cape. WINETECH is an organisation that seeks to advance the competitiveness of the South African wine industry and ABRIMIX is an organization that invested in the construction of the SSF technology which is under investigation. The method of enquiry in this study is a case study conducted on a selected winery at the Westcoast region in the Western Cape. The key arguments in this study will be framed on the traditional Cost-benefit Analysis framework. The chapter is structured as follows. It starts with the description of the research approach, followed by conceptual framework and its analytical tools adopted in this study. It further discusses the sensitivity analysis, costs of wastewater treatment, data sources and data collection methods, variables included in conducting the CBA and lastly covers the scope of the study and highlights the study limitations.

## 5.2 Research Approach

In pursuit of establishing whether it would be profitable to adopt the Shear Separation Floatation (SSF) equipment to treat the winery wastewater, the study seeks to estimate the economic costs and benefits of employing this technology in a winery. While this study is pursued through the quantitative methods of analysis, it is largely based on the case study of Winery X. The case study method which is used as a pedagogical instrument permits thorough, multi-dimensional examinations of intricate subjects in their real-life settings (Crowe1 et al., 2011). The worth and importance of the case study method is well documented in various fields of research, particularly in social science research. A case study method is particularly applicable as it gives a perspective on the practicality of the proposed waste water treatment method. Unless this method is followed, the specific performance, effectiveness and profitability of the SSF system cannot be accurately estimated.

The underlying condition in this study is that the SSF waste water treatment method is only appropriate and viable if it is financially and economically (environmentally and socially sustainable) profitable. Profitability of the SSF plant will be determined through the cost-benefit analysis (CBA). The CBA is designed to establish the economic viability related to the execution of diverse proposals (Molinos-Senanteet al., 2010). CBA begins from the principle that a project should only be appointed on condition that overall benefits surpass the overall costs. Thus, the project gains are matched with its expenses. The difference will be the net profits (loss) of each option (with or without the WWTP). Thus algebraically expressed as: $NP = \Sigma Bi - \Sigma Ci$. Whereby NP represents the net profit, Bi the benefit element i, and Ci denotes the amount of the cost element i. For an assumed program, should the outcome of the analysis be such that $0 < NP$, then the project is economically feasible and vice-versa. The optimum alternative offers the uppermost net profit (Chen & Wang, 2009).

The adoption of CBA necessitates that costs and benefits are given in the same measurements (units). However, this barely applies in projects where environmental externalities are present. As such monetary units are used to express both costs and benefits and as a tool to homogenize the existing heterogeneity. Thus, the application of CBA is enabled.

**Winery X as a case study: Description**

The SSF project at Winery X started in 2020. At the commencement of the project the research team met with the winery management to discuss the project implementation, operations and its prospects thereof. The research team had more visits to the winery during the course of the pilot project to do experiments and collect data based on the operations and the performance of the SSF plant and the winery at large. Initial experiments included visits during the vintage period (Feb - April 2021/2022) whereby the winery wastewater was collected to perform the necessary experiments. Part of the research team's regular engagements with the winery management included discussions on the financial and economic aspects of the project. Data based on the costs and benefits estimates for the SSF technology was produced by the Winery X team and the research team. The meetings also included dissecting the changes (financial) since the commencement of the pilot project and involvement of the research team. Thus, the quantitative data to conduct the CBA for this study was obtained from cost estimates produced by Winery X together with the research team.

All the quantitative data obtained was captured on Microsoft Excel and the CBA was conducted through Excel models. Reports on the project at Winery X also included non- financial costs and benefits that are difficult to quantify which will be briefly discussed in the following chapters qualitatively.

## 5.3 Conceptual Framework

The cost-benefit technique embraced in this study was instrumental to determine the estimated values of costs and benefits of the proposed SSF system. Cost-benefits analysis (CBA) consists of a number of analytical instruments that are employed to evaluate the financial and economic viability of a recommended investment. The instruments used in this study include Benefits-cost ratio (Profitability index); Net Present Value; Payback Period; Discounted Payback Period; Internal Rate of Return (IRR) method and Modified Internal Rate of Return (MIRR) method as key economic measures of value. Sensitivity analysis will also be conducted to assess the sensitivity of results to changing values of variables.

**Net-Present Value (NPV) Method**

The first technique that was used in this study is the net present value (NPV) approach. This is the current price of the estimated future cash flows subtract the cost (Seth, 2022). It is given by: NPV = present value of cash inflows – principal amount. This equation is therefore expressed as: NPV= $-C0 + \sum \frac{B_t}{(1+r)^t}$ ….. **Equation (5.1)**

According to Maliva (2014), a modified form of the above equation is as follows: NPV = $-C0 + (\sum \frac{B_t}{(1+r)^t} - \sum \frac{C_t}{(1+r)^t})$ …… **Equation (5.2)**

Where *C0* is the investment amount in base year (year 0); $B_t$ symbolises the estimated benefits; and $C_t$ represents the costs in the first year. Then "*r*" represents the cost of capital and "*t*" is the time variable. In addition, in an instance where equal cash flows are assumed in different years, the NPV can be projected using the equation below (Excel Forum, 2020).

NPV = $\frac{CF_0}{r-g}$ – Initial Investment…… **Equation (5.3)**

Here, initial investment denotes the initial outlay price of the entire system, for instance the full price of the SSF technology. Then "*g*" denotes the rate at which the cash flows grow (Hansen, 2020). Yearly cost estimates consisted of operating costs, opportunity costs and maintenance cost and the likes. Expected benefits included desired discharge limits of COD, pH and other parameters. Also, the discount rate was applied to adjust the expenses and benefits into present value terms.

**Decision rule**

The SSF technology is economically viable given that it has a positive NPV, a negative NPV for the SSF would suggest that it is not economically viable.

**<u>Payback Method / Period (PP)</u>**

The study also considered the payback period to estimate the length of time the SSF system will take to recompense itself. The PP is calculated as: the initial investment over the annual cash inflows. Below is the formula to estimate the payback period.

Payback Period: PP = $\frac{Initial\ Investment}{Annual\ Cash\ Flows}$ …… **Equation (5.4)**

Put differently, the PP is computed by dividing the overall cost of the SSF by the expected net-benefits. Here, the yearly cash flows denote the expected net-benefits (savings subtract the costs).

**Decision rule**

The shortest payback period is preferred, it is better for a project to yield returns in a shorter period than in an extended period.

**<u>Discounted payback method / period (DPP)</u>**

The discounted payback method is used for the same purposes as the payback method. This method allows the estimated cash flows to be discounted in present value terms so as to produce more robust results (Hansen, 2020). To compute the discounted payback period one must divide the initial investment of the project by the present value of the annual cash flows. Also, the present value of yearly cash flows must be determined first. The present value of the yearly cash flows is calculated through the use of the compound interest formula (USAID, n.d).

Present value of Annual Cash Flows = $\frac{Future\ Value\ of\ Annual\ Cash\ Flows}{(1+i)^n}$…… **Equation (5.5)**

Where "*i*" denotes the discount rate expressed as a decimal; and "*n*" dented the number of interest periods such years, semester, quarter etc. Then, the projected DPP can be determined by the following equation:

Discounted Payback Period: DPP = $\frac{Initial\ Investment}{Present\ Value\ of\ Annual\ Cash\ Flows}$…… **Equation (5.6)**

**Decision rule**

The shortest discounted payback period is preferred and the opposite is true.

**<u>Internal Rate of Return (IRR) Method</u>**

The internal rate of return method is another useful tool that was employed in this analysis. This is useful to establish whether the cost of capital of the SSF technology overshadows its IRR. The IRR can be calculated by the following equation (Excel Forum, 2020).

Internal Rate of Return: IRR = $\frac{Cash\ Flows}{Initial\ Investment} + g$…… **Equation (5.7)**

Where "*g*" denotes the growth rate of the cash flows. If cash flows are assumed to grow constantly by the equal amount, the IRR can be calculated in this manner. However, if cash flows differ year-to-year, it is best to estimate the IRR by means of Microsoft Excel calculations (Hansen, 2020).

**Decision rule**

Normally, the rule for the IRR is that it must be higher than the discount rate to accept the project, otherwise reject the project.

**<u>Modified Internal Rate of Return (MIRR) Method</u>**

The MIRR method is implemented to complement the IRR. It is instrumental and is employed in this study to account for the IRR downsides. The MIRR will provide more robust results or outcome, in the sense that it upholds an assumption that the cash flows are reinvested at the cost of capital. The MIRR can be computed through the following steps: Start by estimating the present value of the costs (PVC) related to the project, by means of cost of capital (r) as the discount rate:

PVC = $\sum_{t=0}^{n} \frac{Cash\ Flow^t}{(1+r)^t}$ …... **Equation (5.8)**

Then, estimate the terminal value (TV) of the cash inflows anticipated from the project:

TV = $\sum_{t=0}^{n} Cash\ flow_t\ (1+r)^{n-t}$…… **Equation (5.9)**

Lastly, find the MIRR, by solving the following equation:

PVC = $\frac{TV}{(1+MIRR)^t}$ …….. **Equation (5.10)**

These equations were used in this study to determine the value of MIRR for the SSF technology.

**Decision rule**

A project in which MIRR is higher than its cost of capital is accepted and rejected when the MIRR is lower than the cost of capital.

**<u>Profitability Index (PI)</u>**

The profitability index will be used to assess the profitability of using the SSF system for effluence treatment instead of the current system. According to Ermenyi (2015), the PI is estimated using the equation below:

Profitability Index: PI = $\frac{Present\ value\ of\ future\ cash\ flows}{Initial\ investment} = 1 + \frac{NPV}{Initial\ investment}$ … **Equation (5.11)**

**Decision rule**

If the PI is above 1.0; then it is worth investing on the project, hence consider investing. On the other hand, if the PI is below 1.0; it is not worth investing, therefore do not invest. In contrast, if the PI is equal to 1.0, one would be indifferent as to accept or reject the investment.

## 5.4 Sensitivity Analysis

This study also conducted sensitivity analysis to test the impact of changing variables to the results. The significance of CBA is fundamentally subject to considering the presence of uncertainty in the analysis. Analysis that directly tackle uncertainty and report a variety of assessments in sensitivity analyses are most expedient. They afford in-depth information for advanced analysis and elucidation by decision makers (Hernández-Sancho et al., 2015). A sensitivity analysis can establish the minimum and maximum value a variable has to offer for a program to appear worthwhile (Song et al., 2015). To achieve more robust results and account for the possible errors

in the NPV, IRR and BCA as might be implicated by uncertainty in the future cash flows, discount rate and other parameters were varied, while *ceteris paribus* is applied in all other variables. Sensitivity analysis was performed by changing the value(s) of discount rate (high, medium and low) based on given assumptions to detect the sensitivity of the results to the changing value of the discount rate. The value for operating costs was likewise transformed. Given the uncertainty in the estimates of the prices, values were varied by 50% above values and 50% below values (Ingle, 2014).

This process is also known as the "What If" analysis. The different assumptions are given by the scenarios below:

What if the interest rates decline by 50, 100 and 150 basis points?

What if the interest rates increase by 50, 100 and 150 basis points?

What if the operating costs reduce by half (50%)?

What if the SSF technology has an economic lifespan of 10 years?

What if fine rates (for compliance) of R6/$m^3$, R8/$m^3$and R10/$m^3$ are imposed?

## 5.5 Cost of wastewater treatment process

Realising the costs and benefits of a project is one of the utmost important steps in economic analysis. The following step is to quantify them, then value them in monetary terms. Overall costs evaluated are classified into internal costs (capital and other operating costs) and external costs (externalities: environmental costs and social costs) of installing the SSF plant in the Winery X community. The assessment procedure was dedicated to the valuation of all the costs involved in the process of waste water treatment.

### 5.5.1 Internal costs

The WWTP costs are grouped in to five categories which are: energy cost, staff costs, reagents, waste costs and cost of maintenance. Energy costs ($x_1$) comprises of the overhead costs linked to the energy consumption (power term) and the variable amount (energy consumption) of the installation. Staff costs ($x_2$) comprises of wages. The word reagents ($x_3$) represents the cost of the

reagents necessary for water and sludge. Waste costs ($x_4$) contain the costs related to waste and sludge management. Lastly, the maintenance cost ($x_5$) is accounted for which includes equipment and machinery maintenance.

Given that the WWTP operating costs are generally subject to the effluent quality, treatment types can be distinguished into: (i) primary/pre-treatment which includes screening, crushing and sedimentation to eliminate the floating and settleable solids contained in wastewater, (ii) secondary treatment which is achieved through a biological method and sedimentation permitting the removal of biological material that is either colloidal in size or dissolved, and (iii) tertiary treatment which allows the elimination of particular contaminants not usually removed through the orthodox secondary treatments such as nutrients and pathogens. This study is mainly focusing on the costs related to primary treatment process through the application of the proposed SSF method.

### 5.5.2 External costs and benefits

The wastewater treatment process is categorised by a preferred output production; treated water ($u_1$), and four outputs that need to be kept at a specific range: suspended solids (SS) ($u_2$), chemical oxygen demand (COD) ($u_3$), nitrogen (N) ($u_4$), and (pH) ($u_5$). Be that as it may, the calculation of the environmental benefits (in monetary terms) resulting from wastewater treatment is more intricate as opposed to calculating costs, as these benefits are not represented by the market. As per Hernandez et al. (2010), calculation of some environmental benefits would be possible by computing the shadow prices of undesirable outputs which are by-products of wastewater treatment. In this study, a proxy for the calculation of environmental costs is the introduction of fine structure, whereby fines are levied on the winery effluent charged for non-compliance. Wastewater treatment can be perceived as a production process whereby an anticipated output (treated water) is acquired together with a number of pollutants (organic matter, phosphorus, and nitrogen, etcetera). Toxins removed from wastewater are considered unwanted outputs because if they were discharged in an unrestrained manner they would have a harmful impact to the environment.

### 5.5.3 Non-monetised potential costs

Considering the main challenges around Winery X wastewater: the unpleasant smell that affects the town and neighbouring areas and the legal compliance issue, some hidden indirect costs would

have been incorporated. These costs include: i) Environmental costs, ii) Tourism & conservation, iii) Local property market, and iv) Social related costs. However, due to time constraints and the process involved in determining these costs, they could not be determined.

## 5.6 Data sources and description of variables

**Data sources and processes**

To achieve the first objective of this study which is focusing on the impact of the wine industry to the South African and Western Cape economy, reports extracted from the South African Wine Industry Information and Systems (SAWIS, 2019-2021), Wines off South Africa (WoSA), Wine Industry Network (WIN), VinPro and other related sources were used. The second research objective that investigates the importance of water and wastewater treatment practices in the wine industry was also addressed through reflecting on the literature studies in this area.

The more specific and the third research objective is based on determining the economic costs and benefits of implementing the SSF technology. Given the nature of the study and the study design which is based on a specific case study, the main data sources for this research includes, experiential data of the SSF plant implementation and cost projections of WWWT process.

In specific terms, costs related to the increasing treatment infrastructure and the costs related to the SSF wastewater treatment plant were determined through the field data acquired by the South African Institute of Advanced Material Chemistry (SAIAMC) in partnership with the University of the Western Cape (UWC) at Winery X. The data obtained is based on both the wastewater treatment system currently used by Winery X and the performance of the proposed SSF technology archetype installed at Winery X. The key methods of system experiments in which the data was collected are coagulation and flocculation methods. SAIAMC further gathered data on the estimated costs for the waste water treatment processes of the proposed treatment plant and the key costs involved in the Winery X waste water treatment process. Among other costs, these include the initial cost of treatment, amount of water consumption, labour costs and other related costs and benefits.

In addition, cost estimates for option Two and Three were also established based on industry data (quotes) comparison received from various companies including: Go Water Management, Two Oceans Projects and Aurecon. These companies were approached through email communication

to enquire about the cost estimates to upgrade the existing and implement a new wastewater treatment system. Given that the machines come in different sizes (with the investigated) varying from 5000 l/h up to 10 000 l/h, the expression of aggregate and partial expenses (costs) is established based on the capacity of the plant. Plant capacity determines which treatment procedures are ranked from least to most expensive (small capacity are less costly and bigger capacity are more costly). As such costs (including operation and maintenance costs per annum, construction costs and project costs) and energy costs can be given by the function of flow rate (Gratziou et al, 2006).

Data obtained revealed that the capital costs range from R450 000 to R600 000 depending on the amount of the automation desired and the capacity of the plant. Therefore, it was established that option Two which involves upgrade with flotation device between the alkalisation pit and dam C, would have an inferred capital cost of R600 000, working with a flow rate of 20 000 l/h. When RO system is included in the wastewater treatment process, the value would increase by an estimated amount of R500 000. Hence, option Three which is extension of option Two with an inclusion of RO system would have an estimated capital costs of R1 100 000. The estimated value of R500 000 for RO system was extrapolated from industry data from websites such as Puritech, Pure Aqua and The Water Company. Data from the aforementioned company websites indicate that they are roundly R500 000 depending the capacity of each RO system and the flow rate for worked on for option Three was 10 000 l/h.

According to Gratziou et al. (2006) each expense contributes a certain percentage to the total operating costs. In fact, a study by Venkatesh and Brattebø (2011) suggested that chemicals and energy for wastewater treatment and water make up an average of 10.8% of the total operational expenses in the water supply sub-system. On these basis, 10% of the capital amount for both options Two and Three will cover electricity bill (power consumption) changes of the membrane and service agreement of the system. The additional running costs of R100 000 for option Two includes the supplementary amount of flocculants required to run the flotation system. Then, R 150 000 additional costs for option Three includes the R100 000 for option Two plus R50 000 (10% of the R500 000 RO system) amounting to R150 000.

Furthermore, since the commencement of the project at Winery X which includes the involvement of the UWC and SAIAMC in fighting the wastewater treatment challenges at the winery, the team

already helped the winery reduce lime consumption. The winery saw a reduction of lime usage value by roughly 23% to 25% of the lime costs, water savings and value of water re-use which was calculated based on the 75% of treated effluent. Further data used in this study for CBA calculations included inflation rate which was then obtained from online data sources from StatsSA and the prime rate of the last quarter of 2022 as determined by the South African Reserve Bank (SARB).

**Description of variables**

**Initial investment/initial outlay (-C0)**

This is the principal amount required to upgrade the Winery X wastewater treatment technology, either for option 2 or option 3. No capital investment required for option 1.

**Costs (-Ct)**

This variable includes the operating costs, and opportunity costs.

**Operating costs**: currently, the wastewater treatment process at Winery X consists of cost of chemicals related to effluent treatment (lime, bacteria, and calcium carbonate) and other operating costs (service agreement, solid sludge removal, electricity cost of effluent, salaries, and maintenance on pH on pumps). However, costs for option 2 and option 3 include annual maintenance and additional running costs.

**Opportunity cost:** this is the potential forgone gains from an alternative. In this instance, the opportunity cost is the amount of money Winery X would save, if they decide not to upgrade their current system with the SSF technology.

**Cost of capital (r/i):** is the cost that arise in a business entity to finance business operations. It measures the rate of return to the creditors or owners on the capital amount contributed. The prime rate according to the South African Reserve Bank (SARB) is currently 10.5% and is used as the discount rate in this study. Prime rate is used because as an established commercial business Winery X borrows from the commercial banks and banks use the prime rate as a benchmark for loans to their top clients.

**Time period (n/t):** is the period of time in which the CBA is conducted. In this study, analysis is conducted over a period of 5 years first, then 10 years.

**Inflation rate:** is a rate at which the price of commodities increase over a specific period of time. The Consumer Price Index (CPI) is the most recognized indicator for inflation. As such, the operating costs increase annually as a result of inflation. Thus, in this study, an inflation rate of 4.8% is used as the growth rate.

**Fines imposed for non-compliance:** fine structure was introduced to determine the minimum value that will result to profits in the implementation of the SSF at Winery X. As already indicated earlier in this chapter, fine rates of R6/$m^3$, R8/$m^3$and R10/$m^3$ were imposed on the effluent discharged by Winery X 49 000$m^3$. These are the estimated rates in the occasion that the winery continues to emit wastewater above compliance levels. If the winery complies, they can avoid these costs, as such costs are avoided are equal to benefits. See calculations in chapter 6.

**Benefits (Bt)**

This includes all the possible gains from upgrading the Winery X wastewater treatment technology or not upgrading. The quantitative benefits are given in per annum values. Non-quantitative are qualitatively discussed. Benefits consists of lime saving costs, water savings, water recovery and fine savings and some environmental and social benefits.

## 5.6 Scope and limitations

This study sought to determine the economic feasibility of implementing the Shear Separation Floatation (SSF) technology deployed by ABRIMIX (owner) in collaboration with SAIAMC of the University of the Western Cape designed to improve efficiency for the wastewater treatment at the Winery X as required by WineTech. This includes improving the winery wastewater discharge compliance levels, reduce the undesired output and cost reduction.

The main limitation to this study is that which is generally linked to the nature of the CBA, which is that findings are solely founded on estimates. Secondly, the other significant limitation, is that apart from the proxy for environmental costs and benefits (fines for noncompliance), study could not estimate most external costs which would have broadened the scope of the study to provide more general and robust results. Finally, although the CBA findings of this study maybe useful for similar future studies, it cannot necessarily be generalized to the entire industry as it only considers one winery (Winery X).

# CHAPTER 6: ANALYSIS OF RESULTS

## 6.1 Introduction

This chapter addresses the third study objective by conducting the CBA analysis to estimate the costs and benefits of deciding whether to upgrade the current wastewater treatment plant at Winery X. This chapter first estimates the costs and benefits of installing the Shear Separation Flotation (SSF) at Winery X. It mainly reveals what would happen if Winery X did nothing but continue discharging effluent at levels beyond compliance levels. In this case, Winery X has three options to consider, thoroughly discussed below. Different scenarios are considered to determine the viability of the proposed system through sensitivity analysis.

## 6.2 Estimating the costs and benefits of upgrading the Winery X effluent treatment plant

The cost-benefit analysis method with its estimation tools is anticipated to assist the Winery X management team in understanding the upsides and downsides of remaining with the current system used for the winery effluent treatment (involving alkalisation with lime followed by aerobic digestion before irrigation to the natural field) or to upgrade the wastewater treatment plant. In parallel, this analysis method seeks to guide the team in understanding the possible benefits and limitations of adopting a new system to improve their environmental wastewater compliance levels. It further seeks to guide the policymakers such as those of the Department of Environmental and Water Affairs on drafting and executing water and environmental pollution policies and making decisions regarding them. Winery X has an average wine production capacity of 30000 $m^3$/a and treats close to 50000 $m^3$/a of winery wastewater. While the ratio between wine and waste is still commendable (many wineries doing far worse), Winery X is currently confronted with compliance challenges, where it must comply with legal effluent discharge standards. For instance, the pollution levels at Winery X are currently 2000 ppm, and the legal limit is 400 ppm. Also, data collected from Winery X indicated that in 2020, Winery X vineyards discharged effluent with a chemical oxygen demand (COD) and electrical conductivity (EC) that exceeded limits for nine months, and potential hydrogen (pH) that exceeded limits for three months. Nonetheless, presently-the winery does not incur any compliance costs; the municipality only acknowledges their efforts to comply with the limits.

Apart from complying with legal standards, Winery X effluent also produces strong odour, which should be eliminated. The winery discharge the treated water to the field as it is not portable or reusable. As such, Winery X approached WineTech for a solution to these issues. WineTech, in partnership with the University of the Western Cape proposed an adoption of a new wastewater system.

Winery X first read about the University of the Western Cape's research efforts in winery wastewater treatment technology in a WineTech Magazines and asked for assistance. The research team at UWC ended up selecting Winery X as the most promising research site to test an advanced flotation technology as part of its research funded through WineTech. In 2020, a research partner in the project discussed a commercial arrangement to treat winery wastewater, but this agreement could not find financial justification. Earlier in 2022, a new solution was proposed that will increase the overall wastewater treatment efficiency at Winery X and put the winery in the position to consider water reuse, potentially reducing their freshwater reliance by at least 50%. The design of the proposed treatment system upgrade is based on experiments performed at a laboratory scale and will significantly improve the quality of the treated effluent. Some investment is needed to execute the proposed solution which intrinsically presents a risk. The cost-benefit analysis focuses on the economic viability of implementing the proposed plan.

This segment deliberates three options that Winery X can consider;

1. The first option is to keep the existing system and make no changes.
2. The second option is to upgrade the existing system with a flotation device, improving the treated wastewater quality.
3. The third option is to upgrade the existing system with a flotation device and a Reverse Osmosis unit, which will improve the quality of the treated wastewater and reduce the reliance on freshwater intake by at least 50%.

A cost-benefit analysis case is established below (Section 6.3) to thoroughly understand which option would be most beneficial to the winery. The subsections below describe each option in more detail.

### 6.2.1 Option One – Keeping the existing system with no upgrades

Suppose the Winery X decides to keep the existing system without any improvements. In that case, they will continue producing wastewater components (COD, EC, and pH) that exceed municipal legal limits. Also, the winery will likely continue to emit odour, a nuisance to their surrounding areas. The positive aspect of keeping the current system with no upgrades is that Winery X will not have to spend on upgrading the system, saving the equivalent amount required to upgrade the system. While Winery X currently has no compliance costs, if the winery continues producing effluent that harms the environment and society, the consequences might be even harsher in the long run. For instance, constantly producing effluent that is harmful to the environment might eventually result in heavy fines imposed on the winery. Therefore, keeping the existing system without upgrades might be costly and undesirable. Winery X may want to explore other options that would be more beneficial to the winery.

### 6.2.2 Option Two: Upgrading the current system to comply with the municipal limits

This system upgrade involves the installation of a flotation device between the alkalisation pit and dam C (See Appendix E for Winery X winery layout). Winery X would have to invest R300 000. UWC will add R300 000 from a donor investor based on this investment. This amount sums up to R600 000 (please see section 5.6 for methods). In addition to the capital investment, the winery would have to spend R60 000 (R600 000 capital cost*10%) on yearly maintenance and an additional operating cost of R100 000 to keep the plant running (Included in these costs are chemicals, service agreement and electricity). Table 1 below have chemicals for calcium carbonate for R132 211 and it was established that the efforts by UWC together with SAIAMC already aided the winery to cut roughly 25% of their chemical use. Therefore, the additional operating cost of R100 000 were calculated as: R132 211*25% = R33 052.75, then R132 211 - R33 052.75 = R99 158.25 ≈ R100 000. So operating cost would be roughly R30 000 less, thus additional operating costs have an inferred value of R100 000.

The projected returns on this system upgrade include treated winery wastewater with COD levels of 2000mg/L and Suspended Solids below 100mg/L. Secondly, foul odours are expected to be eliminated. Also, as already previously discussed this process includes an amount of about 23% to 25% chemical (lime) savings given by a round figure of R30 000 in Table 2. This was estimated

as using the formulas [R132 211*25% = R33 052.75] and [R132 211*23% = R30 408.53 ≈ R30 000]. Some water savings can be expected as the automation of the alkalisation pit will generate lime water at a higher concentration level, which results in some water savings of R5000 (See Table 6.2 below).

### 6.2.3 Option Three: Upgrading the current system to comply with the municipal limits and reuse the effluent

This process is an extension of Option Two to achieve maximum results. It entails the same investment, maintenance and operating cost as Option Two plus the cost related to the reverse osmosis (RO) system (R500 000 capital cost + R100 000 p.a maintenance and electrical cost). As such, the capital amount for Option Three includes the capital of Option Two plus capital costs for RO system (R600 000 + R500 000) = R1 100 000. Annual maintenance has an estimated value of R110 00 which is the [R1 100 000* 10%] estimated based on literature (please see section 5.6). Additional running costs includes the running costs for Option Two R100 000 plus 10% of the RO system (R500 000 * 10% = R50 000) which is R100 000 + R50 000 = R150 000.

Option Three is the only one expected to eliminate the compliance issues they are currently confronted with at the Winery X. The reverse osmosis (RO) system would also turn 75% of wastewater into high-quality water. Provided that the water recovery is estimated to be 75% of treated effluent 49 000 $m^3$/a which is (49 000 $m^3$/a * 75% = 36 750 $m^3$/a). Thus, 36 750 $m^3$/a* R1.5 $m^3$ = R55 125 (R1.5 is a cube price of water, see Table 1). This is how the estimated value of water reuse in Table 2 was determined. In addition to Option Two's benefits, the purpose here is to be able to reuse the effluent and cut the freshwater intake by at least 50%.

## 6.3 Cost Benefit Analysis

Table 6.1 constitutes Scenario 1 and deals with the cost of treating winery wastewater using an existing system. Based on the quality and quantity of the wastewater, this water should not be irrigated onto barren land. The municipality does not inflict any penalties but insists on an annual improvement of the situation.

**Table 6.1: Breakdown of costs estimates related to the wastewater treatment process (kR/a, R/m$^3$, R/a)**

| 2022 Treatment cost estimates | Amount (R/a) | Amount (R/a, R/m3) |
|---|---|---|
| **Chemicals applied at the Winery X treatment process** | | |
| Chemicals related to effluent treatment (R/a) - Lime | 140847 | |
| Chemicals related to effluent treatment (R/a) - Bacteria | 154602 | |
| Chemicals related to effluent treatment (R/a) - CaCo3 | 132211 | |
| **Total Chemicals related to effluent treatment (R/a)** | **427660** | |
| **Other operating costs** | | |
| Service agreements (Nuno Bubblers) (R/a) | 56428 | |
| Solid/sludge removal (Lime ponds) (R/a) | 6334 | |
| Electricity cost effluent (Nuno bubblers and pumps) (R/a) | 21479 | |
| HR - salaries for temp workers during harvest | 49185 | |
| Maintenance on pH instruments (R/a) | 10005 | |
| Maintenance on pumps and motors (R/a) | 30533 | |
| **Total expenses to run the wastewater treatment plant (R/a)** | **601623** | |
| Throughput of the wastewater treatment plant (m3/a) | | 49000 |
| Running cost of treatment plant in R/m3 effluent | | 12.28 |
| Water cube price (m$^3$) | | 1.5 |
| **Total** | | **601720** |

*Source: (Winery X, 2021)*

Table 6.1 above presents the Winery X annual cost structure for their current wastewater treatment process. This process generally includes chemicals, service agreements, labour, electricity and maintenance. According to Winery X, chemical usage forms the most significant part of the running costs (R427 660). The remaining operating expenses, including maintenance, labour, electricity, and service agreements, amount to R173 963. The total running costs in 2022 (R601 623) are divided by the total volume of wastewater treated in 2022. The resulting figure shows the running cost normalised to treated wastewater volume: R12.28/m$^3$.

**Table 6.2: Project Data - Breakdown of costs and benefits of the three possible options**

| *(Per annum values)* | Costs (Negative) | | | Benefits (Positive) | | |
|---|---|---|---|---|---|---|
| | Option 1 **Base Case (No System upgrade)** | Option 2 **Upgrade with Flotation Device between the Alkalisation pit and Dam C** | Option 3 **Upgrade with Floatation Device + Reverse Osmosis** | Option 1 **Base Case (No System upgrade)** | Option 2 **Upgrade with Flotation Device between the Alkalisation pit and Dam C** | Option 3 **Upgrade with Floatation Device + Reverse Osmosis** |
| Investment cost | 0 | -R600 000 | -R1 100 000 | | | |
| Annual maintenance (10% of capital) | 0 | -R 60 000 | -R 110 000 | | | |
| Additional Running costs | 0 | -R100 000 | -R 150 000 | | | |
| Lower cost for COD discharge | | | | 0 | 0 | 0 |
| Total cost of chemicals (R/a) | R427 660 | 0 | 0 | | | |
| Other operating expenses wastewater treatment plant (R/a) | R173 964 | 0 | 0 | | | |
| Value of lime savings | | | | | R 30 000 | |
| Value of water savings | | | | | R 5 000 | R 5 000 |
| Value of water reuse | | | | | | R 55 125 |
| | | | | | | |
| Financial instruments used in the calculations | | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Economic lifespan of the plant | | 10 years | 10 years | | | |
| Warranty | | 5 years | 5 years | | | |
| Prime rate @ | | 10.50% | 10.50% | | | |
| Inflation | | 4.80% | 4.80% | | | |
| Base year | 2022 | | | | | |
| Treated effluent ($m^3$/a) | 49 000 | | | | | |
| Water recovery (75%) of treated effluent | | | 36750 | | | |

*Source: author's calculations using data obtained from Winery X winery, industry, StatsSA and SARB*

Table 6.2 depicts the costs and data concerning implementing the system that The University of the Western Cape proposes to Winery X to eliminate compliance issues, cut costs (cost savings) and reduce the unpleasant smell resulting from the effluent. To effectively implement the proposed project (option 3), a capital expenditure of R1 100 000 would be required as an initial investment. Additional running costs are estimated to amount to R150 000. Maintenance is kept at 10% of the initial investment (R110 000).

The expected savings include lime dosing savings, water savings resulting from water recovery, and lower costs for COD discharge (See fine structure discussions below in section 6.4.4). The plant is expected to run for 10 years and has a warranty of 5 years.

**Table 6.3: CBA results for primary economic measures**

| **Period** | **5 Years** | | |
|---|---|---|---|
| **Discount rate** | **10.50%** | | |
| **Inflation rate** | **4.80%** | | |
| **Options** | **Option 1** | **Option 2** | **Option 3** |
| **Initial Investment** | **R0** | **(R600 000)** | **(R1 100 000)** |
| **Cash flow** | **(R601 623)** | **(R125 000)** | **R251 415** |
| **NPV** | (R2 455 543) | (R1 110 191) | (R73 842) |
| **IRR** | - | - | 8% |
| **MIRR** | -100% | -100% | 9% |
| **PI** | - | -0.85 | 0.93 |
| **Viability** | Not viable | Not viable | Not viable |
| **Period** | **10 Years** | | |
| **Discount rate** | **10.50%** | | |
| **Inflation rate** | **4.80%** | | |
| **Options** | **Option 1** | **Option 2** | **Option 3** |
| **NPV** | (R4 339 811) | (R1 501 688) | R713 584 |
| **IRR** | - | - | 23% |
| **MIRR** | -100% | -100% | 16% |
| **PI** | - | -1.50 | 1.65 |
| **Viability** | Not viable | Not viable | Viable |

*Source: author's calculations*

Table 6.3 above presents the primary economic measures and initial cases for Options One, Two, and Three. The without-project scenario (base case) is represented by Option One. Calculations are based on 5 and 10 years with discount and growth rates of 10.50% and 4.80%, respectively.

The CBA results reveal negative Net-present values for all three options in the short term given by 5 years. While the Net-present value for Options One and Two remain negative after 10 years, Option Three generates a positive Net-present value. Payback periods, discounted payback periods, and the internal rate of return could not be estimated, except for the internal rate of 8% for Option Three, which is less than the discount rate of 10.5% after 5 years but higher (23%) than the discount rate after 10 years. The modified internal rate of return is less than the discount rate for all options after 5 years; after 10 years, only Option Three yields a modified internal rate of return (16%) higher than the discount rate. The profitability index could not be estimated for Option One and is less than 1 for Option Two and Three after 5 years but more than 1 at 1.65 for Option Three after 10 years. Given these results, all three options yield negative returns after 5 years—however, Option Three yields positive returns after 10 years, indicating that the option is viable.

## 6.4 Sensitivity analysis

A sensitivity analysis is conducted for all three alternatives; as such, the CBA results for sensitivity analysis are presented in a tabular form below for all three alternatives to show the "with project" scenario and "without project" scenarios. While the results of changes in interest rates for Option Three (with project scenario) are displayed in Tables 6.4 and 6.5, the results for the scenario of changes in interest rates for Options One and Two are shown in Appendix F – I. This is because the focus is on the "with" and "without" the proposed project results. This kind of analysis is also known as the "What If" analysis. Different scenarios are introduced to test the results' sensitivity to the different values of the input variables.

### 6.4.1 What if the interest rate declines by 50, 100 and 150 basis points?

Table 6.4 below presents the economic measures for decreasing interest rates, with 50, 100 and 150 basis points. The ceteris paribus principle is maintained. Put differently, all the other variables remain the same; only the interest rate varies.

**Table 6.4: CBA results for declining interest rates – Option Three**

| Initial Investment | R1 100 000 | | | |
|---|---|---|---|---|
| Cash flow | R251 415 | | | |
| Period | 5 Years | | | |
| Discount Rate | 10.50% | 10.00% | 9.50% | 9.00% |
| NPV | (R73 842) | (R60 263 ) | (R46 397) | (R32 238) |
| MIRR | 9% | 9% | 9% | 9% |
| PI | 0.93 | 0.95 | 0.96 | 0.97 |
| Viability | Not viable | Not viable | Not viable | Not viable |
| Period | 10 Years | | | |
| Discount Rate | 10.50% | 10.00% | 9.50% | 9.00% |
| NPV | R713 584 | R755 881 | R799 685 | R845 063 |
| MIRR | 16% | 16% | 16% | 15% |
| PI | 1.65 | 1.69 | 1.73 | 1.77 |
| Viability | Viable | Viable | Viable | Viable |

*Source: author's calculations*

Table 6.4 above presents the declining interest rates for Option Three. When the interest rates are assumed to be declining, Table 6.4 above shows negative Net-present values after 5 years. The payback period, discounted payback period, and internal rate of return could not be estimated. The modified internal rate of return of 9% is less than the discount rate (10.5%), and the profitability index (ranges between 0.93 and 0.97) is below 1. After 5 years, the investment into upgrading the Winery X treatment process remains impractical and unattractive. However, given the decreasing interest rates after 10 years, the results indicate positive Net-present values, modified internal rates of return (15% to 16%) that are higher than the discount rates (9% to 10.5%), profitability indexes (1.65 to 1.77) for differing rates greater than 1. These results imply that Option Three will not be profitable over 5 years of declining rates. It would instead start bearing fruits after 10 years. Estimations for Option One and Two in the declining interest scenario also yielded non—viable outcomes (See Appendix F and G).

### 6.4.2 What if the interest rates increase by 50, 100 and 150 basis points?

Table 6.5 below displays the economic measures in the scenario of increasing interest rates, with 50, 100 and 150 basis points, keeping all the other variables constant.

**Table 6.5: CBA results for increasing interest rates – Option Three**

| Initial Investment | R1 100 000 | | | |
|---|---|---|---|---|
| Cash Flow | R251 415 | | | |
| Period | 5 Years | | | |
| Discount Rate | 10.50% | 11.00% | 11.50% | 12.00% |
| NPV | (R73 842) | (87 142) | (R100 171) | (R112 936) |
| IRR | 8% | 8% | 8% | 8% |
| MIRR | 9% | 9% | 9% | 10% |
| PI | 0.93 | 0.92 | 0.91 | 0.90 |
| Viability | Not viable | Not viable | Not viable | Not viable |
| Period | 10 Years | | | |
| Discount Rate | 10.50% | 11.00% | 11.50% | 12.00% |
| NPV | R713 584 | R672 729 | R633 257 | R595 110 |
| IRR | 23% | 23% | 23% | 23% |
| MIRR | 16% | 16% | 17% | 17% |
| PI | 1.65 | 1.61 | 1.58 | 1.54 |
| Viability | Viable | Viable | Viable | Viable |

*Source: author's calculations*

Table 6.5 above presents the results of the CBA analysis in a scenario whereby the interest rates are increasing. This analysis was done on all three given alternatives. While the results for Option Three are presented in Table 6.5 above, the results for Option One and Two are presented in Appendices H and I. Given the rising discount rates for the three options, the Net-present value remains negative after the first 5-year period for all increasing rates. While this is also the case for Option One and Two, after 10 years, the Net-present value for Option Three is positive. Payback periods, discounted payback periods, and the internal rate of return could not be estimated for all three options, except for the internal rate of return for option 3, which is less than the discount rate after 5 years and higher than the discount rate after 10 years. The modified internal rate of return is less than the discount rates, and the profitability index is less than 1 for option 1. Similar results for Options One and Two presented in Appendices H and I transpired, whereby the modified

internal rate of return is below the discount rate. The profitability index could not be predicted for Options One and Two when discount rates are assumed to increase. Therefore, after 5 years, increasing discount rates for Options One, Two and Three yield results that are not economically viable, but after 10 years, Option Three would be a viable option.

### 6.4.3 What if the running costs decrease by 50%?

If the running costs for the three given alternatives were to halve, costs for Option One would be R300 612, for Option Two, the amount for running costs would be R80 000, and half of the running costs for Option Three would amount to R130 000. Specific results for Option One, Two and Three are presented in Table 6.6 below. See Appendices J-L for when the running costs halve at increasing rates.

**Table 6.6: CBA results when running costs halve**

| Period | 5 Years | | |
|---|---|---|---|
| Discount rate | 10.50% | | |
| Inflation rate | 4.80% | | |
| Options | Option 1 | Option 2 | Option 3 |
| Initial Investment | R0 | (R600 000) | (R1 100 000) |
| Cash flow | (R601 623) | (R125 000) | R251 415 |
| NPV | (R1 226 957) | (R783 669) | R456 757 |
| IRR | - | - | 25% |
| MIRR | -100% | -100% | 18% |
| PI | - | -0.31 | 1.42 |
| Viability | Not viable | Not viable | Viable |
| Period | 10 Years | | |
| Discount rate | 10.50% | | |
| Inflation rate | 4.80% | | |
| Options | Option 1 | Option 2 | Option 3 |
| NPV | (R2 168 466) | (R924 608) | R 1 651 339 |
| IRR | - | - | 37% |
| MIRR | -100% | -100% | 21% |
| PI | - | -0.54 | 2.50 |
| Viability | Not viable | Not viable | Viable |

*Source: author's calculations*

If the running costs halve, as indicated in Table 6.6, the NPV, IRR, MIRR, and PI results for Options One and Two do not indicate any significant change; they remain almost the same with the primary scenario outcome for all three options. These imply that if the running costs decrease by 50%, the Net-present values calculated under varying discount rates remain negative after the 5-year and 10-year periods for Options One and Two. Likewise, Options One and Two show MIRRs that are less than the discount rate. Whereas Option Three results in a positive NPV, IRR and MIRR are higher than the discount rate, and PI is higher than 1. PP, DPP and IRR could not be estimated for Option One and Two; only the PP and DPP could not be determined for Option Three. Finally, while the profitability index outcome for Option Two is below 1, the value could not be determined for Option One. Thus, halving the running costs for Options One, Two and Three would still result in a nonviable investment for Option Two, an undesirable outcome for Option One and an auspicious outcome for Option Three as the results suggest it would be economically viable.

### 6.4.4 Introduction of fine (penalty) structure

Further sensitivity analysis is conducted through the introduction of the fine structure. As discussed in the earlier chapters, wineries have to comply with the legal standards for wastewater discharge such that their COD, pH, EC and the like are acceptable. Not complying may result in fines being imposed by the local authorities. Similar to the previous sensitivity analysis sections discussed above, this section will introduce changing values for the variable fine (penalty). Fine values are applied to Options One and Two, none on Option 3 to evaluate which among the three options is worth pursuing. The values of estimation applied are R6/$m^3$, R8/$m^3$ and R10/ $m^3$. These values are charged at the treated effluent of 49 000 $m^3$ /a and are applied alternatively between the three given options to show which option is economically feasible. The assumption is that the municipality penalises the winery's non-compliance. The current system used at the winery (Option One) is charged a 100% fine of the effluent amount, and Option Two is charged 50% of the effluent. In contrast, if the winery selects Option Three (SSF), it will comply with the environmental regulations or requirements, and no fine is levied in that instance. Put differently, the fine for Option Three is then charged on 0% of the treated effluent.

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#### 6.4.4.1 What if a fine rate of R6/m$^3$ is imposed on options 1 and 2?

A rate of R6/m$^3$ is multiplied by the total effluent amount of 49000 m$^3$/a to obtain the total value of the fine on the effluent discharged per annum (R6/m$^3$ *49000 m$^3$/a = R 294 000 p.a). The fine value for Option One is therefore R 294 000p.a. If the same fine rate of R6/m$^3$ is imposed on option 2, the fine is imposed on only 50% of the total treated effluent (49000 m$^3$/a * 0.5 = 24 500 m$^3$/a). Therefore, Option Two also has fine savings of 24 500 m$^3$/a of treated effluent. Thus, fine savings for Option Two would be 24 500 m$^3$/a* R6/m$^3$ = R 147 000 p.a. Lastly, Option Three is the proposed project (SSF plant) is expected to reduce the current COD levels at Winery X and help the winery avoid any looming fines, as such avoiding paying a fine of R6/m$^3$ on 49000 m$^3$/a treated effluent is technically saving 49000 m$^3$/a * R6/m$^3$ = R 294 000 p.a on fines that would be incurred on the current system. See Table 6.7 below for CBA results.

**Table 6.7: CBA results when R6/m$^3$ fine is imposed**

| Period | 5 Years | | |
|---|---|---|---|
| Discount rate | 10.50% | | |
| Inflation rate | 4.80% | | |
| Options | Option 1 | Option 2 | Option 3 |
| Initial Investment | R0 | (R600 000) | (R1 100 000) |
| Fine imposed (savings) | (R 294 000) | R 147 000 | R 294 000 |
| NPV | (R3 655 514) | (R510 206) | R1 534 282 |
| PP | - | 4.58 Years | 2.7 Years |
| DPP | - | 6.16 Years | 3.26 Years |
| IRR | - | -37% | 55.25% |
| MIRR | -100% | -24% | 31.59 |
| PI | - | 0.15 | 2.39 |
| Viability | Not viable | Not viable | Viable |
| Period | 10 Years | | |
| Discount rate | 10.50% | | |
| Inflation rate | 4.80% | | |
| Options | Option 1 | Option 2 | Option 3 |
| NPV | (R6 460 582) | (R441 303) | R3 555 705 |
| PP | - | 4.58 Years | 2.7 Years |
| DPP | - | 6.16 Years | 3.26 Years |
| IRR | - | -12% | 62.76% |

| | | | |
|---|---|---|---|
| **MIRR** | -100% | -3% | 27.65% |
| **PI** | - | 0.26 | 4.23 |
| **Viability** | Not viable | Not viable | Viable |

*Source: author's calculations*

Table 6.7 above indicates that if a fine rate of R6/m$^3$ is applied, holding all other variables (inputs) constant, the results for Option One and Two show negative NPVs at the end of the first 5 years and even after 10 years. On the other hand, Option Three generates positive NPVs both after a 5-year and 10 years. While measures such as PP, DPP, IRR and PI could not be determined for Option Two (base case) given the fine of R6/m$^3$, Option Two has a PP slightly below 5 years, precisely 4.58 years and a DPP of 6.16 years which is beyond 5 years but less than 10 years; an IRR of -37% and -12% after a 5-year and 10-year period respectively which are significantly below the discount rate of 10.5% and the MIRRs for both Options One and Two are below the discount rate both after the short term of 5 years and a longer term of 10 years. The profitability index for Option Two is less than 1 after 5 years and after 10 years. However, the results for option 3 depict a different outcome. Looking at both the output for 5 years and 10 years, the NPV for Option Three is positive. The PP and DPP are less than 5 years, precisely 2.7 years and 3.26 years consecutively. IRR and MIRR for Option Three in both terms are higher than the discount rate, and the profitability index is greater than 1.

The output or results for option 2 differ slightly from that of Option One. Even so, the critical economic measures of the cost-benefit analysis still exhibit the same viability outcome (not viable). When no fines are imposed on Option Three, results indicate that the proposed project is more economically viable than the current technology. Thus, considering Option Three, when the municipality imposes a fine rate of R6/m$^3$, would be profitable for the winery.

#### 6.4.4.2 What if a fine rate of R8/m$^3$ is imposed on Options One and Two?

A different rate of R8/m$^3$ is imposed on Options One and Two; no fine is imposed on Option Three. The same principle applied in section 6.4.4.1 also applies in this section, whereby a fine is levied on the total treated effluent amount of (49000 m$^3$/a*1) for option One multiplied by R8/m$^3$, whereas R8/m$^3$ is multiplied by only 50% of the effluent (49000 m$^3$/a * 0.5) for Option Two, and Option Three incurs no fine costs but saves the whole amount that would be paid by the winery

for fine (49000 $m^3$/a*1), to obtain the total value of the fine on the effluent discharged per annum. The amount that would have been a cost of the fine is a benefit free from the fine if Option Three is implemented. Please see Table 6.8 below for the results and appendices P-R for the results given at increasing rates.

**Table 6.8: CBA results when R8/$m^3$ fine is imposed**

| Period | 5 Years | | |
|---|---|---|---|
| Discount rate | 10.50% | | |
| Inflation rate | 4.80% | | |
| Options | Option 1 | Option 2 | Option 3 |
| Initial Investment | R0 | (R600 000) | (R1 100 000) |
| Fine imposed (savings) | (R 392 000) | R 196 000 | R 392 000 |
| NPV | (R4 055 504) | (R310 211) | R1 526 119 |
| PP | - | 4.58 Years | 2.70 Years |
| DPP | - | 6.16 Years | 3.26 Years |
| IRR | - | -12% | 55.04% |
| MIRR | -100% | -4% | 31.51% |
| PI | - | 0.48 | 2.39 |
| Viability | Not viable | Not viable | Viable |
| Period | 10 Years | | |
| Discount rate | 10.50% | | |
| Inflation rate | 4.80% | | |
| Options | Option 1 | Option 2 | Option 3 |
| NPV | (R7 167 505) | (R87 841) | R3 541 278 |
| PP | - | 4.58 Years | 2.70 Years |
| DPP | - | 6.16 Years | 3.26 Years |
| IRR | - | 7% | 62.57% |
| MIRR | -100% | 9% | 27.61% |
| PI | - | 0.85 | 4.22 |
| Viability | Not viable | Not viable | Viable |

*Source: author's calculations*

The value of the variable fine is altered to test the response of the output variables in the model, keeping all other variables constant. If a fine rate of R8/$m^3$ is applied on Option One, Two and none on Option Three, holding all other variables (inputs) unchanged, the outcome is indifferent from that of Table 6.8 above. The results still exhibit a negative Net-present value for Option One and Two at the end of the first 5 years and even after 10 years. The Net-present value for Option

Three remains positive from the first 5-year period of the project and after 10 years as well. Again, the payback period, discounted payback period, internal rate of return and profitability index could not be estimated for Option One (base case). This estimate produces a modified internal rate of return (-100%) that is significantly below the given discount rate for Option One. Option Two produced a payback period and a discounted payback period of 4.58 years and 6.16 years, respectively, which are both less than the term of the project (10 years), while Option Three has a payback and discounted payback periods of 2.70 years and 3.26 years respectively which are both less than 5 years. The internal rate of return and the modified internal rate of return for Option Two are less than the discount rate after a 5-year and 10 years. Although the internal rate of return and the modified internal rate of return for Option Two significantly improved after 10 years (from -12% and -4% to 7% and 9%, respectively), these rates remain lower than the discount rate of 10.5%.

On the other hand, Option Three resulted in the internal rate of return and a modified internal rate of return that are significantly higher than the discount rate from the first 5 years and after 10 years. While Option Two resulted in profitability indexes of 0.48 and 0.85 after 5 years and 10 years, respectively, which are less than 1, Option Three produced profitability indexes of 2.39 and 4.22, which are higher than 1 after 5 years and 10 years, respectively. Given the above results, when a fine rate of R8/m$^3$ is imposed on Options One and Two, these alternatives do not meet the requirements of the CBA decision rules while Option Three does; as such, both Options One and Two would not be economically viable, and Option Three results suggest that this option is economically viable and as such an attractive investment.

**6.4.4.3 What if a fine rate of R10/m$^3$ is imposed on option One and option Two?**

This section is not introducing a new phenomenon; it is a further application of a different fine rate on both Options One and Two while applying none on Option Three. Again, a rate of R10/m$^3$ is charged on the 100% of the treated effluent (49000 m$^3$/a*1), while this rate is levied on only 50% of the treated effluent (49000 m$^3$/a * 0.5) for option 2. Table 6.9 below depicts the CBA results for this scenario. Also, see Appendices S-U for the results of increasing rates.

**Table 6.9: CBA results when R10/m$^3$ fine is imposed**

| Period | 5 Years | | |
|---|---|---|---|
| Discount rate | 10.50% | | |
| Inflation rate | 4.80% | | |
| Options | Option 1 | Option 2 | Option 3 |
| Initial Investment | R0 | (R600 000) | (R1 100 000) |
| Fine imposed (savings) | (R 490 000) | R 245 000 | R 490 000 |
| NPV | (R4 455 494) | (R110 216) | R2 334 262 |
| PP | - | 4.58 Years | 2.70 Years |
| DPP | - | 6.16 Years | 3.26 Years |
| IRR | - | 3% | 75.48% |
| MIRR | -100% | 6% | 38.76% |
| PI | - | 0.82 | 3.12 |
| Viability | Not viable | Not viable | Viable |
| Period | 10 Years | | |
| Discount rate | 10.50% | | |
| Inflation rate | 4.80% | | |
| Options | Option 1 | Option 2 | Option 3 |
| NPV | (R7 874 429) | R265 621 | R4 969 552 |
| PP | - | 4.58 Years | 2.70 Years |
| DPP | - | 6.16 Years | 3.26 Years |
| IRR | - | 19% | 80.97% |
| MIRR | -100% | 15% | 31.08% |
| PI | - | 1.44 | 5.52 |
| Viability | Not viable | Viable | Viable |

*Source: author's calculations*

The results in Table 6.8 above are similar to those of the two previous cases in Table 6.6 and Table 6.7. For instance, the Net-present value for Option One remains negative, and the modified internal rate of return is still below the discount rate. All other measures could not be estimated for this option. On the other hand, Option Two produces varying results. During the first 5 years, the Net-present value has a negative value; the value is positive after 10 years. Option Three keeps a positive net present value from the first 5 years and after 10 years. Interestingly, the payback period (4.8 years) and the discounted payback period (6.16 years) for Option Two remained the same as that of the previous scenario, less than 5 years and less than 10 years, respectively. Similarly, the

payback and discounted payback periods for Option Three remained the same, with values of 2.70 years and 3.36 years, which are both less than 5 years.

After 5 years, the internal rate of return and modified internal rate of return for Option Two are 3% and 6%, respectively, less than the discount rate (10%). In contrast, these two rates for option 3 are higher than the discount rate after 5 years and after 10 years. Lastly, after 5 years, the profitability index for option 2 is just below 1 with a value of 0.82 and only above 1 at 1.44 after 10 years. Option Three produced a profitability index of 3.12 after 5 years and 5.52 after 10 years; these are higher than 1. The above results reveal that Option One is not viable; Option Two is only viable in a longer term (after 10 years), whereas Option Three is viable in the short term (after 5 years) and long-term (after 10 years). Therefore, the investment in upgrading the current system to comply with the municipal limits and reuse the effluence is viable and worth the investment

## 6.6 Conclusion

Chapter 6 estimated the costs and benefits of upgrading the Winery X wastewater treatment process considering three scenarios. All three options were tested using financial tools. The analysis for the primary financial tools did not yield favourable results for Options One and Two. For instance, the initial analysis indicated negative Net-present values in varying discount rates in all the periods. At the same time, the internal rate of return, payback period and discounted payback period could not be estimated.

Further analysis was conducted through the introduction of a fine structure. Varying scenarios in sensitivity analysis were conducted. The studied scenarios for Options Two and Three showed viability. However, Option Three, which involves upgrading the current system to comply with municipal limits and reusing the effluence, was more viable than the first and second options.

# CHAPTER 7: DISCUSSIONS

## 7.1 Introduction

This chapter discusses the results of the CBA conducted in Chapter 6 on the three project alternatives provided. Firstly, findings on the outcome of CBA when the primary economic measures were put on the model will be discussed. Secondly, there will be discussions on sensitivity analysis, sensitivity analysis with fine structure, and a summary of implementing the SSF wastewater treatment at Winery X. Finally, there will be discussions on the non-monetary costs and benefits of implementing the SSF plant at Winery X to curb the environmental effects resulting from the winery wastewater and comply with the municipal standards thereof.

## 7.2 Discussions

### 7.2.1 Findings on Primary Economic Measures

The basic analysis included testing the CBA outcome given primary economic measures for Options One, Two and Three. These included a discount rate of 10.5%, inflation rate of 4.8%, a warranty of 5 years and a lifespan of 10 years. As such, the CBA results were calculated in 5-year and 10-year periods. The results based on the 5 years revealed that Options One, Two and Three had negative net-present values of about R2.5 million, R1.1 million, and R73 thousand, respectively. These results imply that in the short run (5-year period), the winery will likely incur more cash outflows than cash inflows in all three alternatives. Also, these results do not meet the decision rule for the Net-present value, which requires a Net-present value to be at least positive. Secondly, while the internal rate of return could not be estimated for options One and Two, the internal rate of return for Option Three (8%) was less than the discount rate (10.5%).

Likewise, the modified internal rates of return for Options Two (-0.8) and Three (9%) were less than the discount rate. Despite the positive internal rate of return and the modified internal rate of return, which are slightly below the discount rate for Option Three, they still failed to satisfy the decision rule, which requires these rates to be higher than the discount rate (See chapter 4 and 5 for CBA decision rules). Lastly, the profitability could not be determined for option One; for options Two and Three, the index values are -0.8 and 0.93, respectively. These values also do not

meet the viability requirement for the profitability index, which requires a profitability index to be at least more than 1. Therefore, based on the Net-present values, internal rate of return, modified internal rates of return and profitability indexes, all three options were not viable to pursue in the short term (5 years). In addition, the decision rules for Options One and Two provided the same outcome after 10 years; as such, these options were not viable and remained unattractive investment options.

On the other hand, in the longer term (10 years), Option Three produced results with a positive Net-present value, internal and modified internal rate of return higher than the discount rate and a profitability index greater than 1, resulting in a viable option. As such, the results reflect that all three options would not be worthwhile investments in the short term (5 years) as they do not yield economically viable outcomes. However, Option Three would be viable for a more extended period of 10 years and may be worth pursuing with a long-term focus than the short-term.

### 7.2.2 Sensitivity analysis

Then, sensitivity analysis was implemented by changing the values of the critical variables. The values were changed to examine further the most economically viable option amid the three possible alternatives to help the Winery X achieve compliance levels and reduce operating costs through water recovery and reuse. The first assumption was that interest rates decreased by 50, 100 and 150 basis points. The results indicated that for all the decreasing rates, only Option Three was viable after 10 years. As such, if interest rates were to decrease in the stipulated manner, it would be economically reasonable to pursue Option Three, although returns will only start showing after 10 years.

Secondly, CBA sensitivity analysis was conducted assuming that the interest rates increase by 50, 100 and 150 basis points. The results here were similar to the previous scenario; in fact, the results were the same regarding the viability of the options. As such, doing nothing (Option One) or pursuing Option Two is not recommended, but exploring Option Three would still have returns even after 10 years. A third case scenario of sensitivity analysis was given by the 50% decrease in operating costs. Again, the outcome showed that Options One and Two were not economically viable. As such, they remain undesirable even if the operating costs would decrease by 50%. On the other hand, the results for Option Three indicated that if the running costs decreased by 50%,

this option would be the most economically feasible and most attractive investment as the results yielded a viable outcome even after only 5 years.

### 7.2.3 Sensitivity of results when fine structure is introduced

The sensitivity analysis was further extended, and the fine structure was introduced to depict the importance of complying with the environmental standards for winery wastewater treatment and discharge. The principle here was that if the winery remains with the current system where it exceeds the legislative COD and pH limits and other winery wastewater components set by The Department of Water Affairs (2013), it risks being charged fines if it continues this way for a longer term. On the other hand, if the winery implements the proposed SSF (Option Three), it could reduce the COD levels to comply with the wastewater discharge requirements and keep fines at bay. Therefore, avoided costs are benefits. Arborea et al. (2017) argue that wastewater administration and purification contain substantial gains (eluded costs). As such, the cost of doing nothing may be considered as gains not realised resulting from expulsing the wastewater with insufficient treatment (Arborea et al., 2017). Put differently, if unpurified or poorly purified wastewater is released directly into the environment, costs arise, or possible gains are forfeited.

Be that as it may, fines of varying rates were imposed on 100% of the treated effluent if the winery remained with its current wastewater treatment system. However, if the winery opts for the second alternative, the fines would only be levied on 50% of the treated effluent. If the winery adopts Option Three (SSF), then it would keep fines at bay and save all the costs that would be otherwise incurred in fines. The results indicated that if fine rates of R6/m$^3$ and R8/m$^3$ are charged on Options One and Two while Option Three avoids these costs, Options One and Two are not viable options to pursue while Option Three is viable. However, if a fine rate of R10/m$^3$ is imposed similarly on options One and Two, the results indicate that option One remains nonviable. In contrast, Option Two is viable only after 10 years, and Option Three is viable in the first 5-year period and after 10 years.

### 7.2.4 Summary of CBA results for implementing the SSF plant at Winery X

Option One (Doing nothing and keeping the current system) generated the same outcome (unviable) through the different assumptions and scenarios. The Net-present values for Option One are negative, and the modified internal rate of return is exceptionally below the discount rate. Option Two (Upgrading the current system to comply with the municipal limits) is only viable in one instance after 10 years, where it yields positive net-present values and internal and modified internal rates of return higher than the discount rate. Therefore, Option Two may not be desirable if the focus is in the short term; however, in the long run, it would yield profitable results.

Option Three (Upgrading the current system to comply with the municipal limits and reusing the effluent) produced a favourable outcome, which showed that the project would be viable in all the given assumptions. However, the findings of the CBA on the primary economic measures indicated that the proposed project would only be profitable in a 10-year term. The same results for sensitivity analysis for increasing and decreasing rates transpired. Apart from that, considering the 5 and 10-year periods of the project under varying discount rates, the results show positive Net-present values, payback periods and discounted payback periods of less than 5 years. In addition, internal rates of return and modified internal rates of return are higher than the discount rates, and the profitability index is greater than 1. Therefore, the investment in upgrading the current system to comply with the municipal limits and reuse the effluence would be viable and worth considering.

Furthermore, keeping the current system means that Winery X would save the funds that would have otherwise been spent on the capital costs and the relevant operating (incremental) costs attached to the system upgrade. However, the winery would lose a significant amount of money on annual fines, which would have been avoided through investing in system upgrades. For instance, if a fine rate of R10/$m^3$ is levied on the treated effluent, doing nothing and keeping the current system would cost Winery X R490 000 p.a of penalty fee on non-compliance levies in addition to other operating costs. Also, the anticipated lime savings and water savings through water recovery and reuse would be forfeited. The winery will suffer this financial burden if they remain with the current system and do nothing. Therefore, Option One produces undesirable outcomes for the winery.

In contrast, with the application of penalties, Option Two (Upgrading the current system to comply with the municipal limits) would save Winery X compliance costs of R245 000 p.a. However, this option would not be profitable for the first 5 years after the investment; it will start generating returns only after 10 years and is only viable after such a period; as such, it is also not an optimal solution. Lastly, Option Three will generate returns to Winery X in less than 5 years, and this option would save the winery fine costs amounting to R490 000 p.a. The results suggest that Option Three is viable within the first 5 years of investment. As such, Option Three is viable in all project periods under varying discount rates.

Therefore, when the fine structure is applied to all given alternatives, Option Three is the viable alternative and is the most promising option for the winery to consider. Upgrading the current system to comply with the municipal limits and reuse the effluence would prevent Winery X from facing heavy fines for non-compliance. In essence, the winery would avoid an additional annual cost of R490 000. Therefore, both in the primary and sensitivity analyses, Option Three is the most viable option and worth considering for investment.

A lesson to learn here is that doing nothing and avoiding the investment costs incurred on a new project may appear as a safe option. However, when all aspects (including long-term business consequences) are considered, it is, in fact, worthwhile to invest in the advancement of the current business system.

Romijn and Renes (2013) alluded that evaded costs by a policy alternative are suffered in the baseline case. These costs are rendered null and void if the proposed measure is implemented as captured as benefits (Romijn & Renes, 2013). Therefore, avoided fines are, in fact, benefits. Hence, when Option Three is in effect, fine costs convert to fine benefits.

### 7.2.5 Non-monetised SSF benefits

Some of the experiential findings (not fully covered in this study) of the SSF experiment indicated a decreased amount of lime application in the wastewater treatment process, water savings, and environmental benefits shown by the improved COD value since the pilot of the SSF. The proposed system is also expected to remove at least 90% of the suspended solids and 30% COD while recovering 75% of treated effluent, amounting to 36750$m^3$/a. These improvements contribute to the elimination of environmental hazards and reduce the unpleasant smell that affects the winery's

neighbouring communities. Therefore, the elimination of the environmental hazards would not only be beneficial to the winery but to the surrounding communities as well.

## 7.3 Conclusions

This chapter discussed the findings of the Cost-benefit analysis based on the primary CBA results and the sensitivity analysis. It was found that Option One would result in Winery X saving all the costs required for the upgrade. However, the winery would still face compliance issues, the emission of an unpleasant smell, severe fines for non-compliance, and complaints from commuters might escalate. Option Two would only solve some of the current issues at Winery X and would only gain returns after 10 years. Option Three yields the most promising outcome. In fact, before and after the inclusion of fine structure, Option Three is viable and is the most auspicious option. The non-monetised SSF environmental benefits also support the viability of option three.

# CHAPTER 8: CONCLUSIONS AND POLICY RECOMMENDATIONS

## 8.1 Introduction

This current chapter delivers the main conclusions of the study. It also offers some recommendations that may be useful to the decision-makers, framing future research on similar studies focusing on implementing wastewater treatment projects.

## 8.2 Main conclusions

This thesis explored the economic feasibility of adopting and applying a new wastewater treatment plant (SSF) at Winery X to improve the winery's pollution compliance levels and reduce costs. This exercise was achieved by examining the economic costs and benefits of the three alternatives: a) keeping the current system and doing nothing, b) upgrading the existing system, and c) installing an advanced upgrade on the existing system. Although this study aimed to estimate the economic costs and benefits of implementing the Shear Separation Floatation, its social costs and benefits could not be covered as they were beyond the study's parameters. As such, only the private costs and benefits were determined in this study, and a proxy (fine variables on noncompliance) was made for environmental costs and benefits.

Analysis was carried out by conducting a cost-benefit analysis on all three alternatives. The initial findings revealed that only option 3, installing an advanced upgrade on the existing system, was viable. Essentially, doing nothing was an undesirable option as it would result in the winery incurring annual costs of over R2.4 million on wastewater effluent costs after 5 years and over R4.0 million after 10 years while continuing to emit undesirable levels of pollutants. Option 2 was likewise unprofitable as it would result in an annual expenditure of approximately R1.1 million. In contrast, option 3 had potential annual returns of about R700 thousand. Therefore, given that option 1 would remain with high cost and environmental issues, and option 2 only eliminate the problem to a certain extent, but option 3 would eliminate the environmental issues and reduce expenditure on operating costs, it would be advantageous for Winery X to consider option 3.

Further analysis included conducting sensitivity analysis and introducing fine structure on all three options. The results showed that upgrading the existing system would only be profitable after 10 years, while option 3, installing an advanced upgrade on the current system, would earn higher returns within a reasonable payback period of less than 5 years. Therefore, this study concludes that if compliance fines were imposed on the pollutants produced by Winery X while the winery continues to exceed compliance levels, it would be advisable to implement the Shear Separation Flotation (SSF) and install an advanced upgrade with reverse osmosis (R.O) on the existing system to overcome its compliance challenges and improve its overall efficiency.

## 8.3 Recommendations for future research

There is a need for more studies on wastewater generation and treatment methods that focus on the wine industry, which assess more than just private costs directly linked to the project. As such, it is recommended that further studies that focus on upgrading wastewater treatment systems are conducted with a broad scope that covers the social costs and benefits and other environmental costs and benefits. It would also benefit the field of economics to have more studies of this nature focusing on the macroeconomic impacts.

Secondly, studies based on economic analysis that incorporate the calculation of social and environmental aspects in other industries are recommended.

Lastly, given that this research was based on a project that only had an economic lifespan of 10 years, it would be interesting to see the results of a similar project with an economic lifespan of more than 10 years (i.e., 15, 20, 25 years, etcetera).

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# APPENDICES

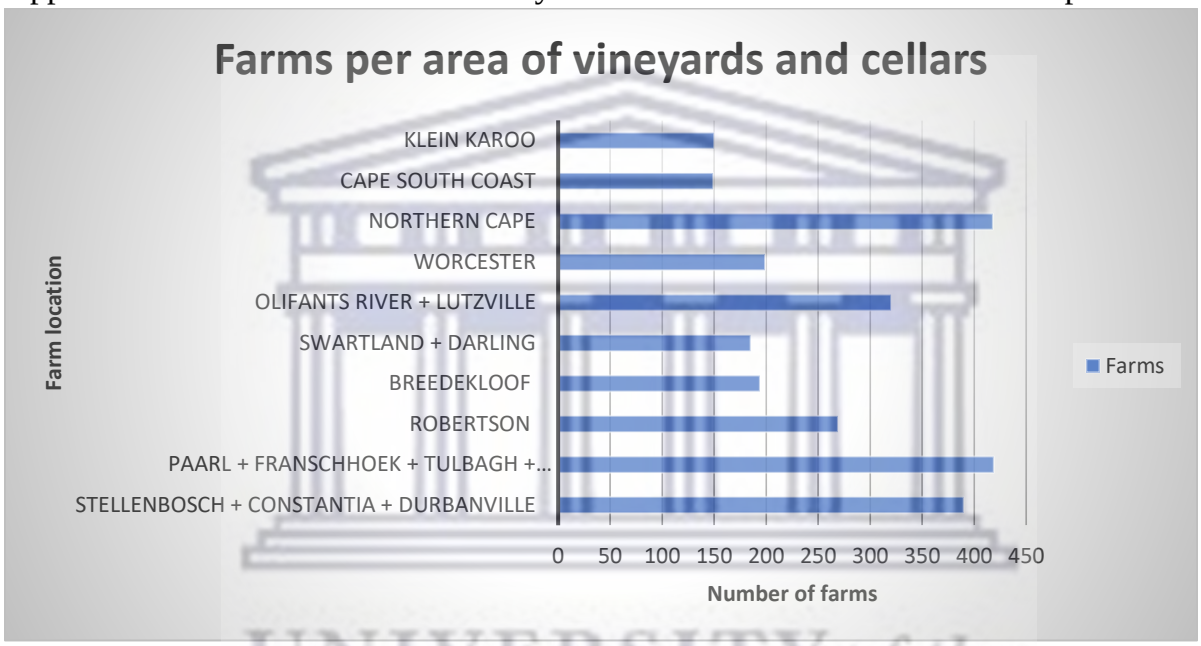
## Appendix A: Other important historical events in development of the South African wine industry

| Year/Period | Historical event |
|---|---|
| **1659** | Jan van Riebeeck – governor of the Dutch in the Cape – tasted his first glass of wine produced locally. |
| **1679** | Simon van der Stel, a Dutch governor, planted the first wine grapes in the Constantia area and later in the Stellenbosch region |
| **1680** | With the arrival in the 1680s of French Huguenot refugees familiar with viticulture and the making of wine and brandy, South Africa's wine industry was launched.. |
| **Early 19th century** | Wine represented almost 90% of all exports from the Cape Colony to Europe (Ponte & Ewert, 2009; Vink, Williams, & Kirsten, 2004). However, the removal of UK preferential tariffs in 1825 threw the industry into depression. |
| **Mid-19th century** | Exports had almost collapsed because of a trade agreement between the UK and France in 1861 (Ponte & Ewert, 2009). |
| **Late 19th century** | Spread of phylloxera destroyed most of the vineyard in the Cape (Chiffoleau et al., 2002). |
| **Early 20th century** | Establishment of the Ko€operatieve Wijnbouwers Vereniging (KWV) – A powerful cooperative with statutory powers to regulate and control the industry. |
| **Throughout 20th century** | Production and consumption of wine have increased. |
| **Late 1980s** | Exports fell to an all-time low because of economic sanctions against South Africa and the KWV had a monopoly on all exports of wine. |
| **Early 1990s** | Sanctions were lifted and at that time, very few South African growers or cellars had any experience of foreign markets. |
| **Mid-1990s to early 2000s** | Renaissance of the industry took place following the opening of international markets, the (relative) novelty of South African table wine and a weak ZAR. However, South Africa was by then playing a game of catch up with countries like Australia and Chile, yet exports grew rapidly. |
| **2005–2006** | 2005 the ZAR had strengthened, there was a red wine 'glut' on the global market, but the outlook had started to change. In 2006, the wine industry witnessed decreasing exports, some bankruptcies and a general decrease in profitability and competitiveness. |
| **2007–2008** | Signs of recovery were detectable in 2007 and 2008 with a new weakening of the ZAR. |
| **2009–2015** | Slow world economy recovery after global downturn (2008–2010), competition in the UK market very strong between wine from RSA and its rivals (Australia, New Zealand and Chile). |
| **2016** | The effect of the new Economic Partnership Agreement between the EU and Southern African Customs Union (Namibia, Lesotho, Swaziland, Botswana and South Africa) |

| | |
|---|---|
| **Mid-2016** | means that RSA can, from 2016, export 110 million litres of duty-free wine to EU countries (up from 48 million litres).<br>June 2016: The UK decided to move out of the EU – Brexit – and South African wine exports now face new challenges. |

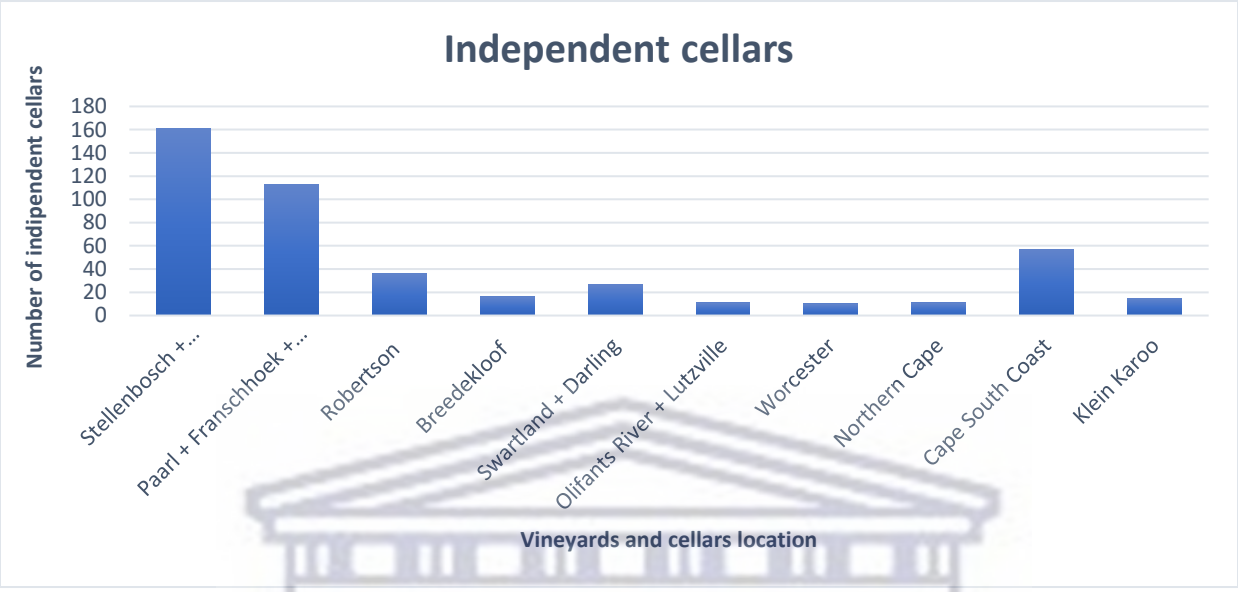
*Source: (Ferreira & Hunter, 2017)*

Appendix B: Number of farms in vineyard and cellar area in the Western Cape



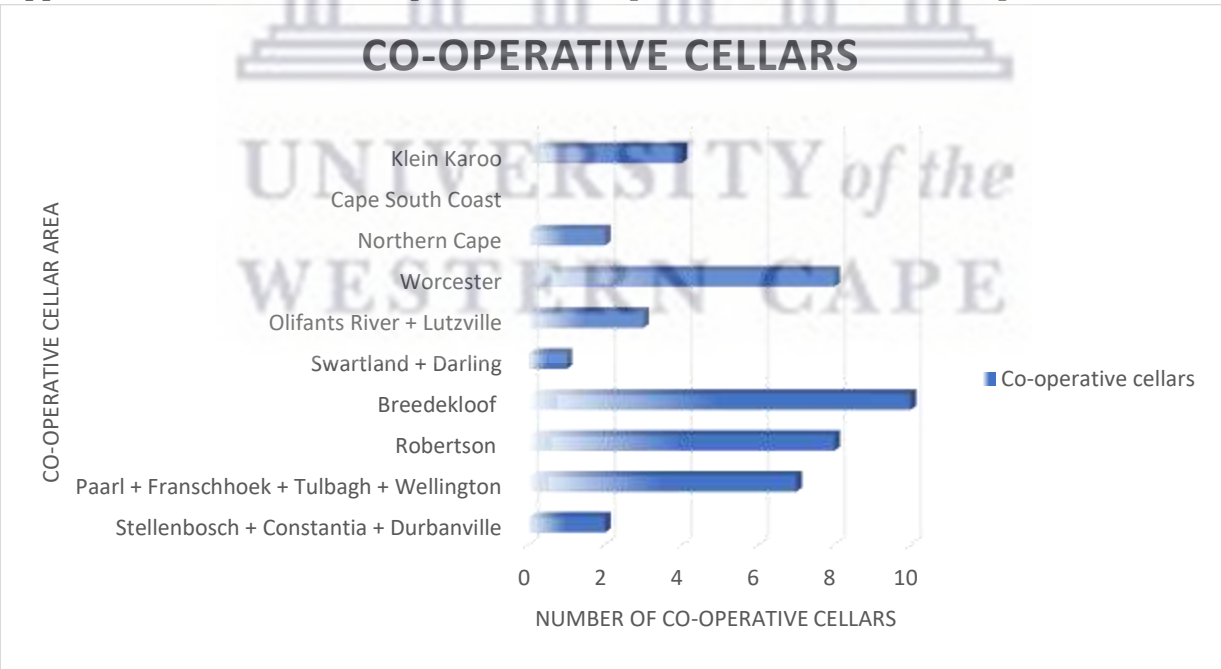

*Source: Owner's computation, data extracted from South Africa's Wine Industry Information & Systems (SAWIS) 2021 report.*

Appendix C: Number of independent cellars per area in the Western Cape region



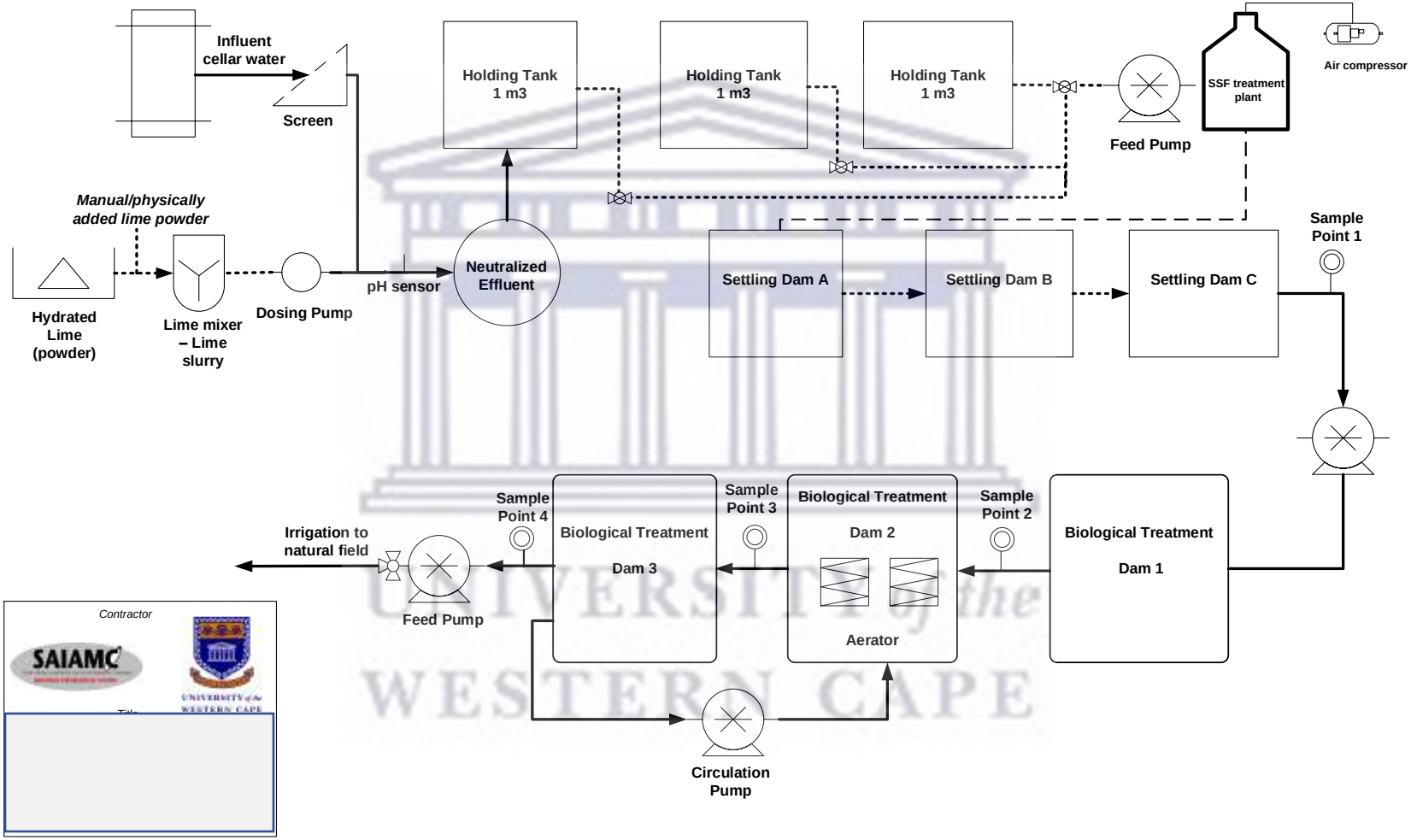

*Source: Owner's computation, data extracted from South Africa's Wine Industry Information & Systems (SAWIS) 2021 report.*

Appendix D: Number of co-operative cellars per area in the Western Cape




*Source: Owner's computation, data extracted from South Africa's Wine Industry Information & Systems (SAWIS) 2021 report.*

Appendix E: Winery X Wastewater treatment process and instrumentation diagram including SSF




*Source: (Vlotman, 2021)*

Appendix F: Declining interest rates for Option 1

| Initial Investment | R0 | | | |
|---|---|---|---|---|
| Time Period | 5 Years | | | |
| Discount Rate | 10.50% | 10.00% | 9.50% | 9.00% |
| NPV | (R2 455 543) | (R2 488 037 ) | (R2 521 217) | (R2 555 100) |
| PP | - | - | - | - |
| DPP | - | - | - | - |
| IRR | - | - | - | - |
| MIRR | -100% | -100% | -100% | -100% |
| PI | - | - | - | - |
| Viability | Not viable | Not viable | Not viable | Not viable |
| Time Period | 10 Years | | | |
| Discount Rate | 10.50% | 10.00% | 9.50% | 9.00% |
| NPV | (R4 339 811) | (R4 441 027) | (R4 545 848) | (R4 654 435) |
| PP | - | - | - | - |
| DPP | - | - | - | - |
| IRR | - | - | - | - |
| MIRR | -100% | -100% | -100% | -100% |
| PI | - | - | - | - |
| Viability | Not viable | Not viable | Not viable | Not viable |

*Source: author's calculations*

Appendix G: Declining interest rates for Option 2

| Initial Investment | R600 000 | | | |
|---|---|---|---|---|
| Time Period | 5 Years | | | |
| Discount Rate | 10.50% | 10.00% | 9.50% | 9.00% |
| NPV | (R1 110 191) | (R1 116 943) | (R1 123 836) | (R1 130 876) |
| PP | - | - | - | - |
| DPP | - | - | - | - |
| IRR | - | - | - | - |
| MIRR | -100% | -100% | -100% | -100% |
| PI | -0.85 | -0.86 | -0.87 | -0.88 |
| Viability | Not viable | Not viable | Not viable | Not viable |
| Time Period | 10 Years | | | |
| Discount Rate | 10.50% | 10.00% | 9.50% | 9.00% |
| NPV | (R1 501 688) | (R1 522 718) | (R1 544 497) | (R1 567 058) |
| PP | - | - | - | - |

| | | | | |
|---|---|---|---|---|
| **DPP** | - | - | - | - |
| **IRR** | - | - | - | - |
| **MIRR** | -100% | -100% | -100% | -100% |
| **PI** | -1.50 | -1.54 | -1.57 | -1.61 |
| **Viability** | Not viable | Not viable | Not viable | Not viable |

*Source: author's calculations*

Appendix H: Increasing interest rate for Option 1

| **Initial Investment** | **R0** | | | |
|---|---|---|---|---|
| **Time Period** | **5 Years** | | | |
| **Discount Rate** | **10.50%** | **11.00%** | **11.50%** | **12.00%** |
| **NPV** | (R2 455 543) | (R2 423 716 ) | (R2 392 538) | (R2 361 992) |
| **PP** | - | - | - | - |
| **DPP** | - | - | - | - |
| **IRR** | - | - | - | - |
| **MIRR** | -100% | -100% | -100% | -100% |
| **PI** | - | - | - | - |
| **Viability** | Not viable | Not viable | Not viable | Not viable |
| **Time Period** | **10 Years** | | | |
| **Discount Rate** | **10.50%** | **11.00%** | **11.50%** | **12.00%** |
| **NPV** | (R4 339 811) | (R4 242 048) | (R4 147 594) | (R4 056 310) |
| **PP** | - | - | - | - |
| **DPP** | - | - | - | - |
| **IRR** | - | - | - | - |
| **MIRR** | -100% | -100% | -100% | -100% |
| **PI** | - | - | - | - |
| **Viability** | Not viable | Not viable | Not viable | Not viable |

*Source: author's calculations*

Appendix I: Increasing interest rate for Option 2

| **Initial Investment** | **R600 000** | | | |
|---|---|---|---|---|
| **Time Period** | **5 Years** | | | |
| **Discount Rate** | **10.50%** | **11.00%** | **11.50%** | **12.00%** |
| **NPV** | (R1 110 191) | (R1 103 579 ) | (R1 097 101) | (R1 090 754) |
| **PP** | - | - | - | - |
| **DPP** | - | - | - | - |
| **IRR** | - | - | - | - |

| | | | | |
|---|---|---|---|---|
| **MIRR** | -100% | -100% | -100% | -100% |
| **PI** | - | - | - | - |
| **Viability** | Not viable | Not viable | Not viable | Not viable |
| **Time Period** | **10 Years** | | | |
| **Discount Rate** | **10.50%** | **11.00%** | **11.50%** | **12.00%** |
| **NPV** | (R1 501 688) | (R1 481 376) | (R1 461 751) | (R1 442 785) |
| **PP** | - | - | - | - |
| **DPP** | - | - | - | - |
| **IRR** | - | - | - | - |
| **MIRR** | -100% | -100% | -100% | -100% |
| **PI** | - | - | - | - |
| **Viability** | Not viable | Not viable | Not viable | Not viable |

*Source: author's calculations*

Appendix J: Running costs decrease by 50%, Option 1: Given at increasing interest rates

| **Initial Investment** | **R0** | | | |
|---|---|---|---|---|
| **Time Period** | **5 Years** | | | |
| **Discount Rate** | **10.50%** | **11.00%** | **11.50%** | **12.00%** |
| **NPV** | (R1 226 957) | (R1 211 054 ) | (R1 195 476) | (R2 361 992) |
| **PP** | - | - | - | - |
| **DPP** | - | - | - | - |
| **IRR** | - | - | - | - |
| **MIRR** | -100% | -100% | -100% | -100% |
| **PI** | - | - | - | - |
| **Viability** | Not viable | Not viable | Not viable | Not viable |
| **Time Period** | **10 Years** | | | |
| **Discount Rate** | **10.50%** | **11.00%** | **11.50%** | **12.00%** |
| **NPV** | (R2 168 466) | (R2 119 618) | (R2 072 422) | (R2 026 810) |
| **PP** | - | - | - | - |
| **DPP** | - | - | - | - |
| **IRR** | - | - | - | - |
| **MIRR** | -100% | -100% | -100% | -100% |
| **PI** | - | - | - | - |
| **Viability** | Not viable | Not viable | Not viable | Not viable |

*Source: author's calculations*

Appendix K: Running costs decrease by 50%, Option 2: Given at increasing interest rates

| Initial Investment | R600 000 | | | |
|---|---|---|---|---|
| Time Period | 5 Years | | | |
| Discount Rate | 10.50% | 11.00% | 11.50% | 12.00% |
| NPV | (R783 669) | (R781 288 ) | (R778 956) | (R776 672) |
| PP | - | - | - | - |
| DPP | - | - | - | - |
| IRR | - | - | - | - |
| MIRR | -100% | -100% | -100% | -100% |
| PI | -0.31 | -0.30 | -0.30 | -0.29 |
| Viability | Not viable | Not viable | Not viable | Not viable |
| Time Period | 10 Years | | | |
| Discount Rate | 10.50% | 11.00% | 11.50% | 12.00% |
| NPV | (R924 608) | (R917 295) | (R910 230) | (R903 403) |
| PP | - | - | - | - |
| DPP | - | - | - | - |
| IRR | - | - | - | - |
| MIRR | -100% | -100% | -100% | -100% |
| PI | -0.54 | -0.53 | -0.52 | -0.51 |
| Viability | Not viable | Not viable | Not viable | Not viable |

*Source: author's calculations*

Appendix L: Running costs decrease by 50% Option 3: Given at increasing interest rates

| Initial Investment | R1 100 000 | | | |
|---|---|---|---|---|
| Cash flow | R251 415 | | | |
| Time Period | 5 Years | | | |
| Discount Rate | 10.50% | 11.00% | 11.50% | 12.00% |
| NPV | R456 757 | R436 580 | R416 814 | R397 448 |
| IRR | 25% | 25% | 25% | 25% |
| MIRR | 18% | 19% | 19% | 19% |
| PI | 1.42 | 1.40 | 1.38 | 1.36 |
| Viability | Viable | Viable | Viable | Viable |
| Time Period | 10 Years | | | |
| Discount Rate | 10.50% | 11.00% | 11.50% | 12.00% |
| NPV | R 1 651 339 | R 1 589 360 | R 1 529 478 | R 1 471 606 |
| IRR | 37% | 37% | 37% | 37% |
| MIRR | 21% | 21% | 22% | 22% |

| | | | | |
|---|---|---|---|---|
| **PI** | 2.50 | 2.44 | 2.39 | 2.34 |
| **Viability** | Viable | Viable | Viable | Viable |

*Source: author's calculations*

Appendix M: R6/m$^3$ fine imposed on option 1: Shown at varying interest rates

| **Initial Investment** | **R0** | | | |
|---|---|---|---|---|
| **Fine imposed** | **- R 294 000** | | | |
| **Time Period** | **5 Years** | | | |
| **Discount Rate** | **10.50%** | **11.00%** | **11.50%** | **12.00%** |
| **NPV** | (R3 655 514) | (R3 608 133) | (R3 561 719) | (R3 516 246) |
| **MIRR** | -100% | -100% | -100% | -100% |
| **Viability** | Not viable | Not viable | Not viable | Not viable |
| **Time Period** | **10 Years** | | | |
| **Discount Rate** | **10.50%** | **11.00%** | **11.50%** | **12.00%** |
| **NPV** | (R6 460 582) | (R6 315 045) | (R6 174 432) | (R6 038 540) |
| **MIRR** | -100% | -100% | -100% | -100% |
| **Viability** | Not viable | Not viable | Not viable | Not viable |

*Source: author's calculations*

Appendix N: R6/m$^3$ fine imposed on option 2: Shown at varying interest rates

| **Initial Investment** | **R 600 000** | | | |
|---|---|---|---|---|
| **Fine savings** | **R 147 000** | | | |
| **Time Period** | **5 Years** | | | |
| **Discount Rate** | **10.50%** | **11.00%** | **11.50%** | **12.00%** |
| **NPV** | (R510 206) | (R511 370) | (R512 510) | (R513 627) |
| **PP** | 4.58 Years | 4.58 Years | 4.58 Years | 4.58 Years |
| **DPP** | 6.16 Years | 6.28 Years | 6.40 Years | 6.53 Years |
| **IRR** | -37% | -37% | -37% | -37% |
| **MIRR** | -24% | -24% | -24% | -24% |
| **PI** | 0.15 | 0.15 | 0.15 | 0.14 |
| **Viability** | Not viable | Not viable | Not viable | Not viable |
| **Time Period** | **10 Years** | | | |
| **Discount Rate** | **10.50%** | **11.00%** | **11.50%** | **12.00%** |
| **NPV** | (R441 303) | (R444 878) | (R448 332) | (R451 670) |
| **PP** | 4.58 Years | 4.58 Years | 4.58 Years | 4.58 Years |
| **DPP** | 6.16 Years | 6.28 Years | 6.40 Years | 6.53 Years |
| **IRR** | -12% | -12% | -12% | -12% |
| **MIRR** | -3% | -3% | -3% | -3% |
| **PI** | 0.26 | 0.26 | 0.25 | 0.25 |
| **Viability** | Not viable | Not viable | Not viable | Not viable |

*Source: author's calculations*

Appendix O: R0/m$^3$ fine imposed on option 3, when R6/m$^3$ is charged on option 1 and 2.

| Initial Investment | R 1 100 000 | | | |
|---|---|---|---|---|
| Fine savings | R 294 000 | | | |
| Time Period | 5 Years | | | |
| Discount Rate | 10.50% | 11.00% | 11.50% | 12.00% |
| NPV | R1 534 282 | R1 500 138 | R1 466 690 | R1 433 921 |
| PP | 2.7 Years | 2.7 Years | 2.7 Years | 2.7 Years |
| DPP | 3.26 Years | 3.30 Years | 3.33 Years | 3.37 Years |
| IRR | 55.25% | 55.25% | 55.25% | 55.25% |
| MIRR | 31.59 | 31.84% | 32.09% | 32.34% |
| PI | 2.39 | 2.36 | 2.33 | 2.30 |
| Viability | Viable | Viable | Viable | Viable |
| Time Period | 10 Years | | | |
| Discount Rate | 10.50% | 11.00% | 11.50% | 12.00% |
| NPV | R3 555 705 | R3 450 826 | R3 349 496 | R3 251 568 |
| PP | 2.7 Years | 2.7 Years | 2.7 Years | 2.7 Years |
| DPP | 3.26 Years | 3.30 Years | 3.33 Years | 3.37 Years |
| IRR | 62.76% | 62.76% | 62.76% | 62.76% |
| MIRR | 27.65% | 27.94% | 28.22% | 28.51% |
| PI | 4.23 | 4.14 | 4.04 | 3.96 |
| Viability | Viable | Viable | Viable | Viable |

*Source: author's calculations*

Appendix P: R8/m$^3$ fine imposed on Option 1 at differing interest rates

| Initial Investment | R0 | | | |
|---|---|---|---|---|
| Fine imposed | - R 392 000 | | | |
| Time Period | 5 Years | | | |
| Discount Rate | 10.50% | 11.00% | 11.50% | 12.00% |
| NPV | (R4 055 504) | (R4 002 939) | (R3 951 446) | (R3 900 998) |
| MIRR | -100% | -100% | -100% | -100% |
| Viability | Not viable | Not viable | Not viable | Not viable |
| Time Period | 10 Years | | | |
| Discount Rate | 10.50% | 11.00% | 11.50% | 12.00% |
| NPV | (R7 167 505) | (R7 006 044) | (R6 850 045) | (R6 699 283) |
| MIRR | -100% | -100% | -100% | -100% |
| Viability | Not viable | Not viable | Not viable | Not viable |

*Source: author's calculations*

Appendix Q: R8/m$^3$ fine imposed on Option 2 at differing interest rates

| Initial Investment | R 600 000 | | | |
|---|---|---|---|---|
| Fine savings | R 196 000 | | | |
| Time Period | 5 Years | | | |
| Discount Rate | 10.50% | 11.00% | 11.50% | 12.00% |
| NPV | (R310 211) | (R313 967) | (R317 647) | (R321 252) |
| PP | 4.58 Years | 4.58 Years | 4.58 Years | 4.58 Years |
| DPP | 6.16 Years | 6.28 Years | 6.40 Years | 6.53 Years |
| IRR | -12% | -12% | -12% | -12% |
| MIRR | -4% | -4% | -4% | -4% |
| PI | 0.48 | 0.48 | 0.47 | 0.46 |
| Viability | Not viable | Not viable | Not viable | Not viable |
| Time Period | 10 Years | | | |
| Discount Rate | 10.50% | 11.00% | 11.50% | 12.00% |
| NPV | (R87 841) | (R99 378) | (R110 525) | (R121 298) |
| PP | 4.58 Years | 4.58 Years | 4.58 Years | 4.58 Years |
| DPP | 6.16 Years | 6.28 Years | 6.40 Years | 6.53 Years |
| IRR | 7% | 7% | 7% | 7% |
| MIRR | 9% | 9% | 9% | 9% |
| PI | 0.85 | 0.83 | 0.82 | 0.80 |
| Viability | Not viable | Not viable | Not viable | Not viable |

*Source: author's calculations*

Appendix R: R0/m$^3$ fine imposed on Option 3 at differing interest rates, when R8/m$^3$ fine is imposed on options 1 and 2.

| Initial Investment | R 1 100 000 | | | |
|---|---|---|---|---|
| Fine savings | R 392 000 | | | |
| Time Period | 5 Years | | | |
| Discount Rate | 10.50% | 11.00% | 11.50% | 12.00% |
| NPV | R1 526 119 | R1 492 081 | R1 458 737 | R1 426 069 |
| PP | 2.70 Years | 2.70 Years | 2.70 Years | 2.70 Years |
| DPP | 3.26 Years | 3.30 Years | 3.33 Years | 3.37 Years |
| IRR | 55.04% | 55.04% | 55.04% | 55.04% |
| MIRR | 31.51% | 31.76% | 32.01% | 32.26% |
| PI | 2.39 | 2.36 | 2.33 | 2.30 |
| Viability | Viable | Viable | Viable | Viable |
| Time Period | 10 Years | | | |
| Discount Rate | 10.50% | 11.00% | 11.50% | 12.00% |
| NPV | R3 541 278 | R3 436 724 | R3 335 708 | R3 238 083 |
| PP | 2.70 Years | 2.70 Years | 2.70 Years | 2.70 Years |
| DPP | 3.26 Years | 3.30 Years | 3.33 Years | 3.37 Years |
| IRR | 62.57% | 62.57% | 62.57% | 62.57% |
| MIRR | 27.61% | 27.90% | 28.18% | 28.47% |

| | | | | |
|---|---|---|---|---|
| **PI** | 4.22 | 4.12 | 4.03 | 3.94 |
| **Viability** | Viable | Viable | Viable | Viable |

*Source: author's calculations*

Appendix S: R10/m$^3$ fine imposed on Option 1 at varying interest rates

| **Initial Investment** | **R0** | | | |
|---|---|---|---|---|
| **Fine imposed** | **- R 490 000** | | | |
| **Time Period** | **5 Years** | | | |
| **Discount Rate** | **10.50%** | **11.00%** | **11.50%** | **12.00%** |
| **NPV** | (R4 455 494) | (R4 002 939) | (R3 951 446) | (R3 900 998) |
| **MIRR** | -100% | -100% | -100% | -100% |
| **Viability** | Not viable | Not viable | Not viable | Not viable |
| **Time Period** | **10 Years** | | | |
| **Discount Rate** | **10.50%** | **11.00%** | **11.50%** | **12.00%** |
| **NPV** | (R7 874 429) | (R7 006 044) | (R6 850 045) | (R6 699 283) |
| **MIRR** | -100% | -100% | -100% | -100% |
| **Viability** | Not viable | Not viable | Not viable | Not viable |

*Source: author's calculations*

Appendix T: R10/m$^3$ fine imposed on Option 2 at varying interest rates

| **Initial Investment** | **R 600 000** | | | |
|---|---|---|---|---|
| **Fine savings** | **R 245 000** | | | |
| **Time Period** | **5 Years** | | | |
| **Discount Rate** | **10.50%** | **11.00%** | **11.50%** | **12.00%** |
| **NPV** | (R110 216) | (R116 564) | (R122 783) | (R128 876) |
| **PP** | 4.58 Years | 4.58 Years | 4.58 Years | 4.58 Years |
| **DPP** | 6.16 Years | 6.28 Years | 6.40 Years | 6.53 Years |
| **IRR** | 3% | 3% | 3% | -3% |
| **MIRR** | 6% | 6% | 7% | 7% |
| **PI** | 0.82 | 0.81 | 0.80 | 0.79 |
| **Viability** | Not viable | Not viable | Not viable | Not viable |
| **Time Period** | **10 Years** | | | |
| **Discount Rate** | **10.50%** | **11.00%** | **11.50%** | **12.00%** |
| **NPV** | R265 621 | R246 121 | R227 281 | R209 073 |
| **PP** | 4.58 Years | 4.58 Years | 4.58 Years | 4.58 Years |
| **DPP** | 6.16 Years | 6.28 Years | 6.40 Years | 6.53 Years |
| **IRR** | 19% | 19% | 19% | 19% |
| **MIRR** | 15% | 15% | 15% | 15% |
| **PI** | 1.44 | 1.41 | 1.38 | 1.35 |
| **Viability** | Viable | Viable | Viable | Viable |

*Source: author's calculations*

Appendix U: R0/m$^3$ fine imposed on Option 3 when R10/m3 fine charged on option 1 & 2: Presented at varying rates

| **Initial Investment** | **R 1 100 000** | | | |
|---|---|---|---|---|
| **Fine savings** | **R 490 000** | | | |
| **Time Period** | **5 Years** | | | |
| **Discount Rate** | **10.50%** | **11.00%** | **11.50%** | **12.00%** |
| **NPV** | R2 334 262 | R2 289 749 | R2 246 144 | R2 203 |
| **PP** | 2.70 Years | 2.70 Years | 2.70 Years | 2.70 Years |
| **DPP** | 3.26 Years | 3.30 Years | 3.33 Years | 3.37 Years |
| **IRR** | 75.48% | 75.48% | 75.48% | 75.48% |
| **MIRR** | 38.76% | 39.02% | 39.29% | 39.55% |
| **PI** | 3.12 | 3.08 | 3.04 | 3.00 |
| **Viability** | Viable | Viable | Viable | Viable |
| **Time Period** | **10 Years** | | | |
| **Discount Rate** | **10.50%** | **11.00%** | **11.50%** | **12.00%** |
| **NPV** | R4 969 552 | R4 832 824 | R4 700 722 | R4 573 054 |
| **PP** | 2.70 Years | 2.70 Years | 2.70 Years | 2.70 Years |
| **DPP** | 3.26 Years | 3.30 Years | 3.33 Years | 3.37 Years |
| **IRR** | 80.97% | 80.97% | 80.97% | 80.97% |
| **MIRR** | 31.08% | 31.37% | 31.67% | 31.97% |
| **PI** | 5.52 | 5.39 | 5.27 | 5.16 |
| **Viability** | Viable | Viable | Viable | Viable |

*Source: author's calculations*